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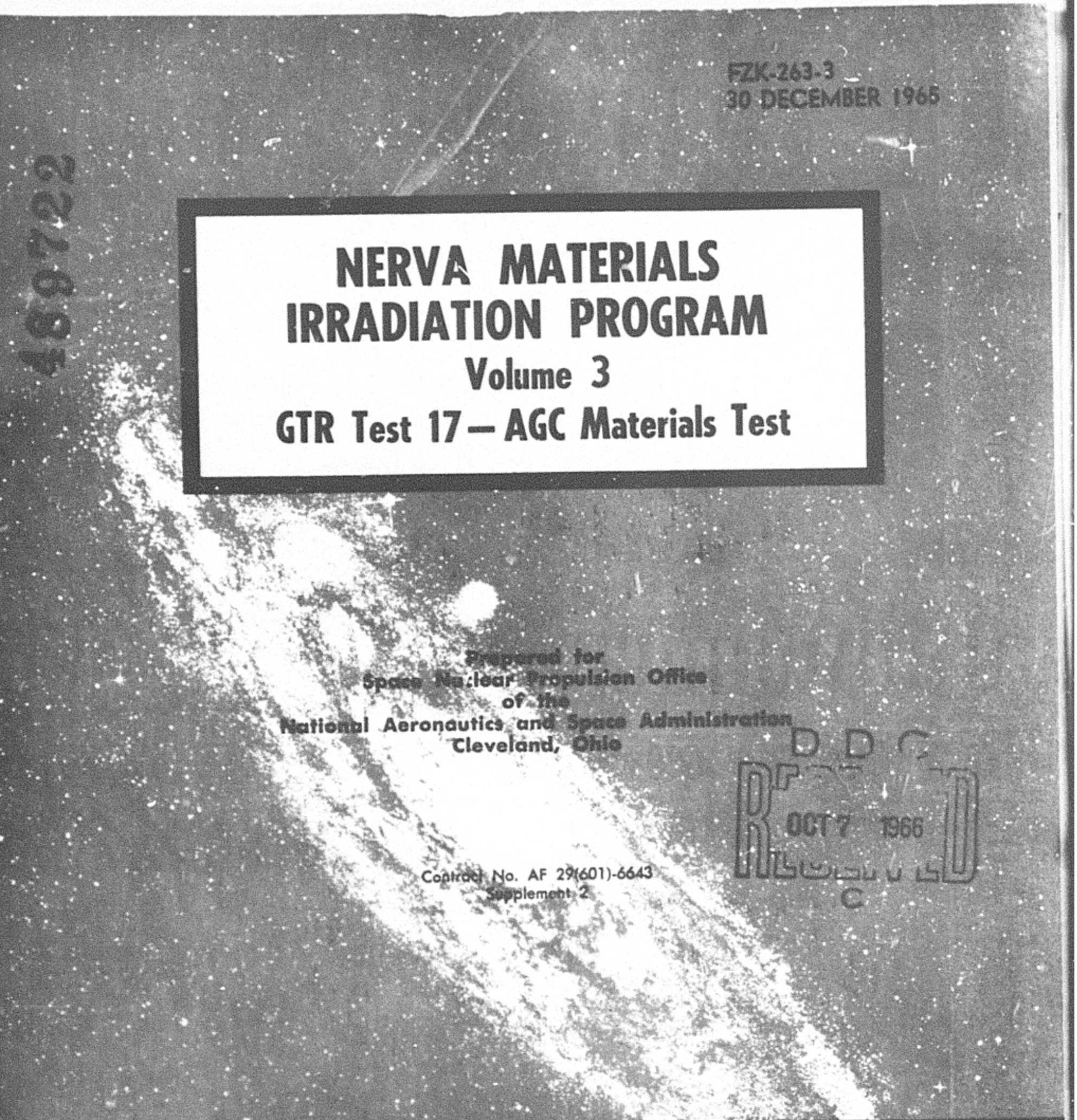

NERVA MATERIALS IRRADIATION PROGRAM

Volume 3

GTR Test 17 — AGC Materials Test

Prepared for
Space Nuclear Propulsion Office
of the
National Aeronautics and Space Administration
Cleveland, Ohio

Contract No. AF 29(601)-6643
Supplement 2

NUCLEAR AEROSPACE RESEARCH FACILITY

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NUCLEAR AEROSPACE RESEARCH FACILITY

NERVA MATERIALS IRRADIATION PROGRAM

Volume 3

GTR Test 17 — AGC Materials Test

H. G. Thornton

37/R102 Tensile Specimens

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GENERAL DYNAMICS | FORT WORTH

ACKNOWLEDGMENTS

The author wishes to acknowledge the participation of several groups and individuals in the performance of this test and the preparation of the report.

C. E. Dixon and L. E. Krelovich were the Aerojet-General Monitors and are to be commended for their cooperation and assistance in the planning and performance of the test.

E. T. Smith is the lead man of the NARF Radiation Effects Materials Group and in this capacity has the responsibility of coordinating, with supervision, all efforts performed by the group.

W. M. Laney, C. G. Pou, and J. D. Stanley were prime contributors to this report in the areas of planning, test operation, and data processing. Numerous other NARF Radiation Effects personnel contributed to this experiment in the areas of design, test operation, and data processing.

W. E. Dungan and W. E. Ivie, Jr., were responsible for the determination of exposure conditions and for the reduction and analysis of dosimetry data.

J. B. Wattier performed the statistical analysis of the stress-strain data.

J. D. Reynolds of the General Dynamics Engineering Test Laboratory performed the x-ray diffraction studies.

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SUMMARY

The purpose of this test was to determine the combined effects of nuclear radiation and liquid hydrogen on the mechanical properties of various organic materials scheduled for use in conjunction with the NERVA propulsion system.

The test consisted of the irradiation and subsequent tensile testing, under several different environmental conditions, of specimens made from the following materials:

1. Armalon TFE-405-CL-116
2. Armalon TFE-405-L-112
3. Armalon FEP-510-L-128
4. Teflon FEP
5. Superpolymer SP-3

The specimens submerged in liquid hydrogen were irradiated in the three cryogenic tensile test assemblies utilized previously in GTR-16 (GD/FW Report FZK-263-1). Three different dose conditions were achieved by varying the irradiation time and the spacing between the test assembly and the reactor. One run was originally scheduled to accomplish all three specified dose conditions, but a damaged LH_2 transfer line necessitated making two separate runs. The predicted gamma and neutron exposures are as follows:

Dose	Assembly Location	Run Time (hr)	Assembly-to-Closet Spacing	Exposure Gamma [ergs/gm(C)]	Exposure Neutrons (n/cm^2, E > 2.9 Mev)
High	North	25	Normal	2.7×10^{10}	5×10^{15}
Intermediate	East	25	19 in.	5.4×10^{9}	7.8×10^{14}
Low	North	1	Normal	1.1×10^{9}	2.0×10^{14}

Analysis of the nuclear measurements made during the test indicates that exposures were achieved that encompass the design, or predicted, dose levels. An analysis and presentation of the exposure profiles is contained in the body of the report.

After the irradiated specimens were tested, control specimens were tested at nearly identical environmental condtions. An analysis of the mechanical property data indicates that the specimens of the three Armalon materials exhibited a high degree of damage at the high-dose condition. A definite, although generally minor, effect was measured at the intermediate level, and no damage was detected at the low dose level. A similar trend was encountered in the Teflon FEP material, except that a more significant effect was detected at the intermediate dose level. The fifth material tested was Superpolymer SP-3, which exhibited no radiation-induced damage at any of the dose levels.

A detailed presentation of the data, along with a statistical analysis, is contained in the text.

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I. INTRODUCTION

GTR Test 17 is a continuation of a series of irradiation tests being conducted at the Nuclear Aerospace Research Facility (NARF) of the Fort Worth Division of General Dynamics for the Space Nuclear Propulsion Office at Cleveland, Ohio (SNPO-C). The purpose of these tests is to determine the effects that a cryogenic and/or nuclear radiation environment has on the components and materials proposed for use in the NERVA engine. The Aerojet-General Corporation (AGC) has prime responsibility for development of the NERVA engine; the nuclear reactor in the engine is being developed by Westinghouse Astronuclear Laboratory (WANL). Previous tests in the series and the associated results are given in References 1, 2, 3, and 4.

The test covered by this document is designated as 37/R102, as set forth in the AGC final test specifications (Ref. 5). These specifications stipulate: (1) the irradiation of organic tensile specimens to three dose levels while submerged in LH_2, (2) the subsequent tensile testing to fracture under different environmental conditions, (3) testing of nonirradiated control specimens under a nearly parallel set of environmental conditions, and (4) x-ray diffraction studies of a selected group of specimens.

A list of the materials tested, the design exposures specified, and a definition of the different environmental conditions is

presented at the beginning of Section II. This is followed by a description of the specimen loading arrangement, the irradiation and testing procedures, and a description of the hardware and instrumentation.

Section III contains (1) a discussion of the methods used for correlating and correcting the data, (2) a presentation and discussion of the property data, (3) a statistical analysis of the data, and (4) a description of the dosimetry used, along with curves showing integrated neutron fluxes and gamma doses to which the specimens were exposed.

The NARF Radiation Effects Testing Facility is described in an Appendix.

II. TEST PROGRAM

The GTR Radiation Effects Testing System at NARF is described briefly in the Appendix and in detail in Section 2 of Reference 6. The GTR is located in a water-filled tank that occupies one-third of a 20- by 30- by 27-ft-deep "swimming pool." The other two-thirds makes up the irradiation test cell. For irradiations, the reactor is traversed into a closet-like structure located midway in the tank wall separating the two areas of the pool. Items to be irradiated may be placed at any or all of the three sides: the north side, with 2 in. of water shielding; or the east and west sides, with 4 in. of water.

2.1 Test Description and Procedures

The test consisted of the irradiation and subsequent testing of approximately 276 tensile specimens and 72 dielectric and elastic-constant specimens made from the following organic materials:

1. Armalon TFE-405-CL-116
2. Armalon TFE-405-L-112
3. Armalon FEP-510-L-128
4. Teflon FEP
5. Superpolymer SP-3

The specimens were irradiated in LH_2 in the three cryogenic test assemblies used in GTR-16. Each assembly was exposed to a different gamma dose, each dose approximating one of the three design exposures. The gamma dose and integrated fast-neutron flux ($E > 2.9$ Mev) predicted for each assembly are as follows:

Dose	Assembly Location	Run Time (hr)	Assembly-to-Closet Spacing	Exposure: Gamma [ergs/gm(C)]	Exposure: Neutrons (n/cm^2)
High	North	25	Normal	2.7×10^{10}	5×10^{15}
Intermediate	East	25	19 in.	5.4×10^{9}	7.8×10^{14}
Low	North	1	Normal	1.1×10^{9}	2.0×10^{14}

2.1.1 Description of Test Conditions

Postirradiation testing was accomplished at several different environmental conditions. For comparison, nonirradiated control specimens (92) were tested at conditions nearly parallel to those of the irradiated specimens. An explanation of each test condition and the symbolic representation of that condition are given below:

Condition 1: LH_2

After irradiation, specimens were tested in LH_2 with no intervening warmup.

Condition 2: $LH_2 \rightarrow GHe \rightarrow LH_2$

After irradiation, the specimens were warmed up to ambient temperature in gaseous helium (GHe). The specimens were held for 4 days in GHe, then returned

to and tested in LH_2. The control specimens at this condition were warmed up and held in air rather than GHe, since oxidation is not considered relevant for nonirradiated specimens.

Condition 3: $LH_2 \rightarrow GHe \rightarrow LH_2 \rightarrow Air \rightarrow LH_2$

These specimens were subjected to the same GHe hold and then returned to LH_2, as described in Condition 2. The specimens were then warmed to ambient temperature, held in air for 4 days, then returned to and tested in LH_2. No control specimens were tested at this condition.

Condition 4: $LH_2 \rightarrow GHe \rightarrow LH_2 \rightarrow Air$

The specimens tested at this condition were subjected to the same environmental sequence as Condition 3, except that the specimens were tested at ambient temperature following the 4-day hold in air.

Condition 5: $LH_2 \rightarrow GHe \rightarrow LH_2 \rightarrow Air \rightarrow 300^{\circ}F \rightarrow RT$

The specimens tested at this condition were subjected to the same environmental sequence as Condition 4. After the 4-day hold in air, the specimens were placed in an oven and subjected to a $+300^{\circ}F$ temperature for 8 hr. The specimens were then cooled and tested in air at room temperature (RT). No control specimens were tested at this condition.

Condition 6: RT as received

Only control specimens were tested in this condition for a temperature-effect comparison. These specimens were tested in air at ambient temperature in the as-received form.

A summary of the specimens tested at the various conditions is shown in Table 2-1.

Table 2-1

Summary Schedule of Test Specimens

Material	Environmental Condition						
	1	2	3	4	5	6	Other
			Control Specimens				
Armalon 405-CL-116	4	4	-	4	-	4	3[a]
Armalon 405-L-112	4	4	-	4	-	4	2
Armalon 510-L-128	4	4	-	4	-	4	4
Teflon FEP	4	4	-	4	-	4	3
Superpolymer SP-3	4	4	-	4	-	4	-
Total	20	20	-	20	-	20	12
			Irradiated Specimens				
Armalon 405-CL-116	4	4	4	4	4[c]	-	6[b]
Armalon 405-L-112	4	4	4	4	4[d]	-	6
Armalon 510-L-128	4	4	4	4	4	-	6
Teflon FEP	4	4	4	4	4	-	6
Superpolymer SP-3	4	-	4	4	4	-	-
Total for Each Assembly	20	16	20	20	16	-	24

[a]Tensile specimens provided with extensometer tabs tested at LH_2 temperature from the "as received" condition.
[b]Dielectric and elastic-constant specimens.
[c]Omitted from high-dose assembly.
[d]Omitted from low- and intermediate-dose assemblies.

2.1.2 Preparation of Specimens

All test specimens were provided by AGC. The specimens were catalogued and their dimensions measured and recorded at NARF. After a loading sequence was specified, as shown in Table 2-2, a detailed loading schedule was prepared and the specimens were identified and grouped accordingly.

2.1.3 Charging and Bleeding of Hydraulic Systems

The hydraulic plumbing for all three assemblies was identical. Each system was charged and bled prior to loading the specimens. A modification has been incorporated in the system since GTR-16 to permit postirradiation bleeding.

2.1.4 Loading of Specimens

All specimens were checked and loaded in accordance with the prepared loading schedule. In each assembly, 14 tensile specimens were installed on each of 4 pull rods, with 5 of these specimens being secured only in the upper clevis. A static rack was provided in each assembly to hold the remaining 36 tensile specimens and 24 "other-property" specimens. A typical specimen loading is shown in Figure 2-1.

2.1.5 Thermal-Cycling and Leak-Checking of Test Assemblies

Each cryogenic materials test assembly was mated to an AGC dewar and all cryogenic plumbing was hooked up and checked. All instrumentation equipment was hooked up and checked out. Each

Table 2-2

Typical Specimen Loading for Each Pull-Assembly Rod

Dynamic Pull Order	Material	Specimen Length (in.)
1	Superpolymer SP-3	9.75
2	Teflon FEP	10.25
3	Teflon FEP	10.75
4	Armalon 405-CL-116	11.25
5	Armalon 405-CL-116	11.75
6	Armalon 510-L-128	12.25
7	Armalon 510-L-128	12.75
8	Armalon 405-L-112	13.25
9	Armalon 405-L-112	13.75
Static - Attached to Upper Clevis Only	Armalon 405-CL-116	9.75
	Armalon 510-L-128	9.75
	Armalon 405-L-112	9.75
	Teflon FEP	9.75
	Superpolymer SP-3	9.75

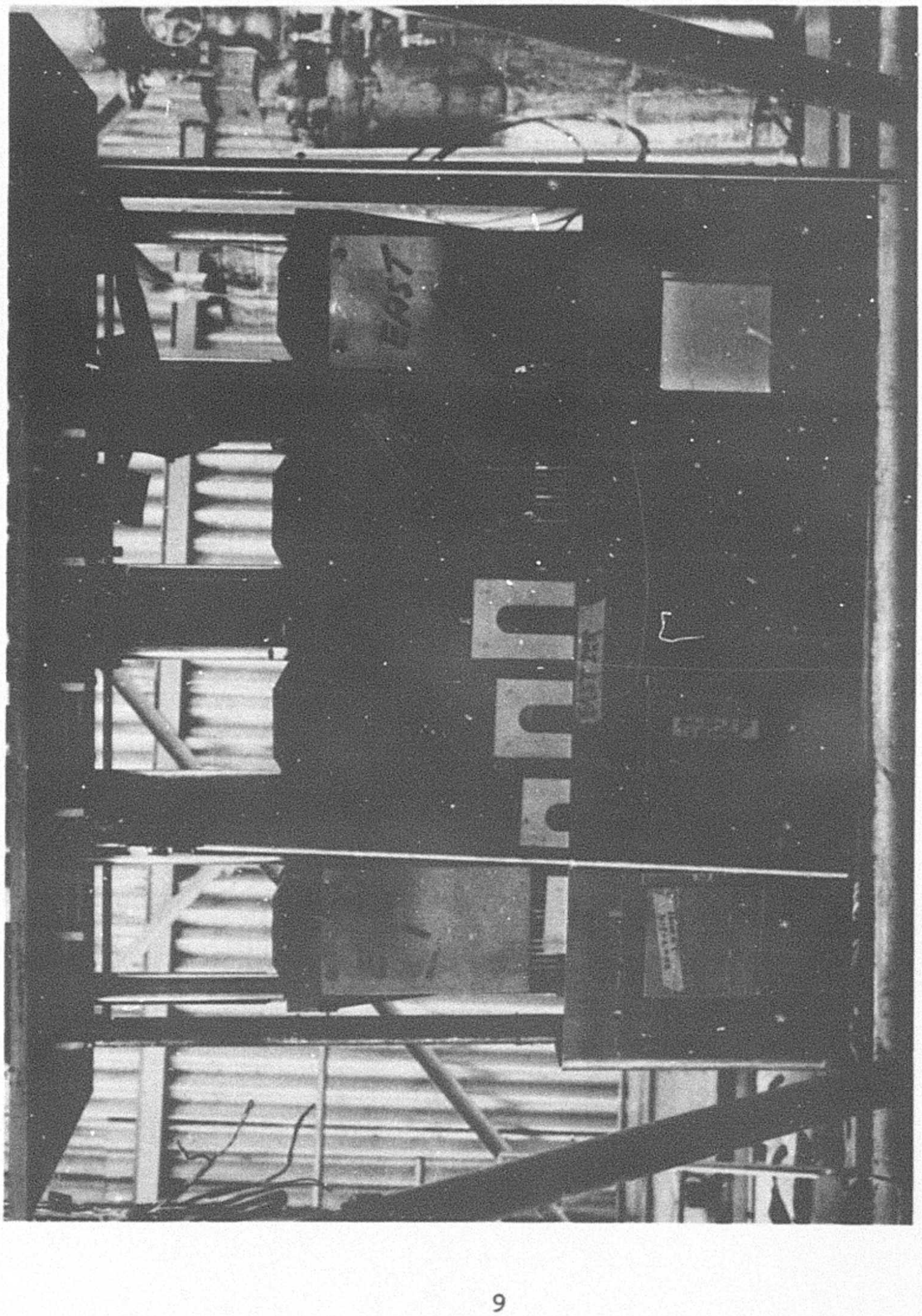

Figure 2-1 Typical Specimen Loading Showing Static and Dynamic Specimens

system was then purged and thermal-cycled twice with LH_2. During each thermal cycle, all seals, gaskets, and fittings were checked for leaks. When each system was approved as being leak-tight, the shroud was installed and pressure-checked.

2.1.6 Final Assembly Checkout in Irradiation Test Cell

The support stand for each assembly was positioned in the test cell adjacent to the reactor closet. The test assemblies were then lowered into position with the overhead crane, as shown in Figure 2-2. Each dewar was filled with LH_2 and the liquid level stabilized. The test cell was then checked for leaks, utilizing the General Monitor detection system. With no detectable leakage, the reactor was brought to a power of 3 Mw outside the closet and slowly traversed into irradiation position 2 in. from the inside of the north face of the closet.

2.1.7 Postirradiation Testing

At the conclusion of the irradiation period, the testing procedure for the tensile specimens was started. Briefly, the typical sequence of operations was as follows:

1. After reactor shutdown, 1 hr was allowed for the temperature and liquid level to reach equilibrium in each assembly and for air activation to diminish.

2. The hydraulic valves on the interconnect panel were positioned to the desired system and the pull rams were bled to remove any gas evolved during irradiation.

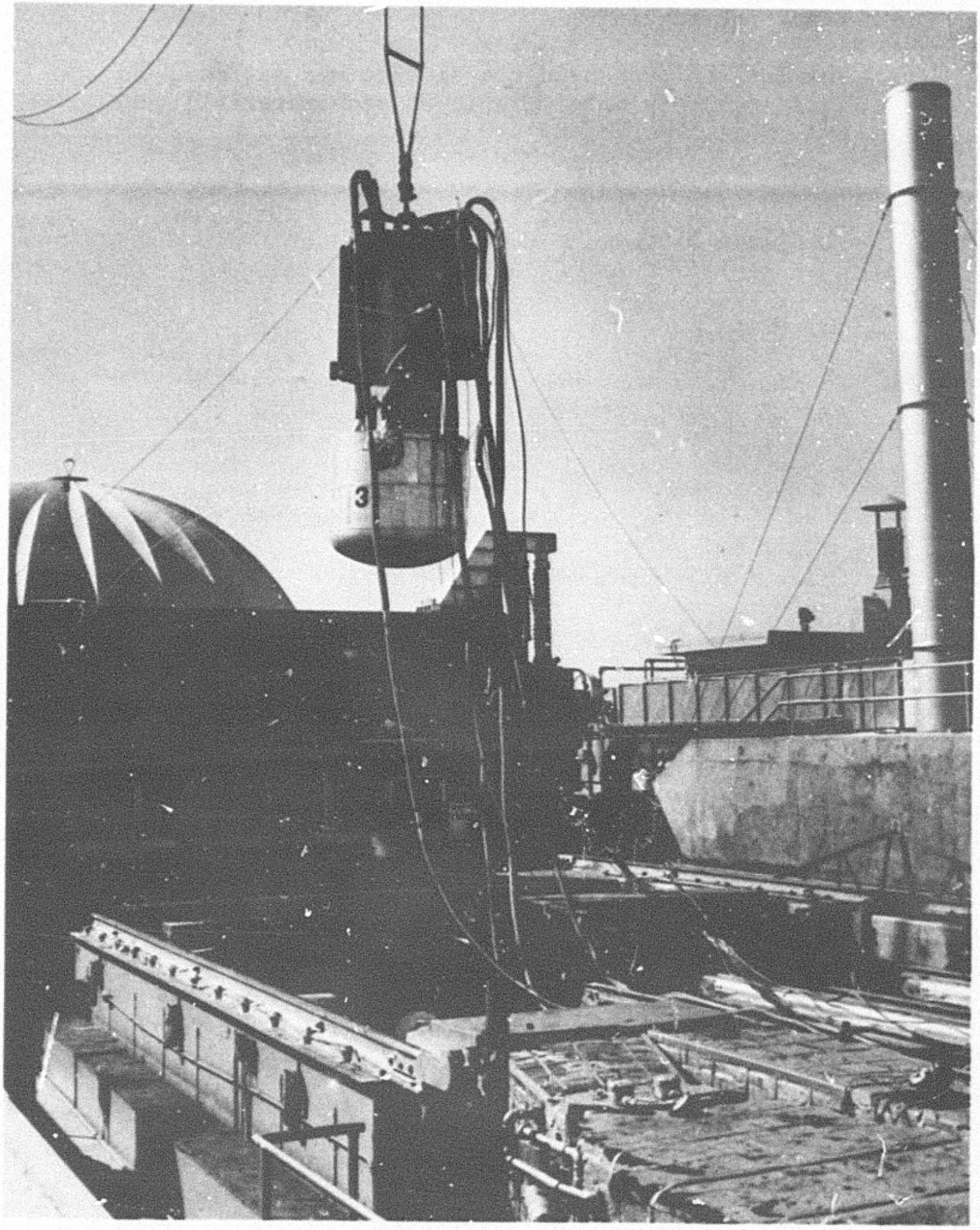

Figure 2-2 Typical Test Assembly Being Installed in the Irradiation Test Cell

3. The Instron tensile-test machine and the data-acquisition system were zeroed, balanced, and made ready for testing.

4. The Instron crosshead travel rate was set at 0.050 in./min, and 20 specimens (4 of each material) were pulled at LH_2 temperature.

5. The LH_2 flow was terminated and the specimens warmed with GHe. After a period of 4 ($\pm$1) days in GHe at ambient temperature, the specimens were again submerged in LH_2 and 16 specimens (4 of each material except Superpolymer SP-3) pulled at this temperature.

6. The test assembly was removed from the test cell and the dewar opened to expose the remaining specimens to air for 4 ($\pm$1) days.

7. Twenty specimens were pulled at ambient temperature in the Instron at a strain rate of 0.050 in./min.

8. Sixteen specimens were warmed to 300°F and maintained at that temperature for 8 hr. They were then cooled to ambient temperature and pulled in the Instron at 0.050 in./min.

9. The remaining 20 specimens that were statically irradiated were loaded in the pulling assembly and, after being submerged in LH_2, were pulled at LH_2 temperature.

The dielectric and elastic-constant specimens were returned to Aerojet-General Corporation for postirradiation testing.

2.1.8 Control-Specimen Testing

Control tests were performed on the same five materials under temperature-environment conditions parallel to the irradiated specimens:

1. Twenty specimens were tested at ambient temperature in the Instron at 0.050 in./min strain rate.

(These specimens were tested in the as-received condition without any thermal cycling having been accomplished).

2. Sixty specimens were loaded in one pull assembly, with 20 specimens installed on the 4 pull rods and the other 40 on the static rack. The dewar was thermal-cycled twice with LH_2.

3. The dewar was refilled with LH_2 and the 20 specimens on the pull rods were tested.

4. The dewar was opened up and the remaining 40 specimens exposed to air for 4 days.

5. Twenty specimens were reloaded on the pull rods and tested at LH_2 temperature.

6. The remaining 20 specimens were then removed from the static rack and tested at ambient temperature in the Instron.

7. Twelve specimens were provided by AGC with gage-length tabs and were tested at LH_2 temperature without thermal cycling. One extensometer mechanism was activated and utilized to measure the strain that occurred between the tabs.

2.2 Test Hardware and Instrumentation

2.2.1 Cryogenic Materials Test Assembly

The test assembly is rated for a load application of 12,000 lb. Each assembly has four pull positions. The tensile specimens are secured between a stationary clevis and a movable clevis at each pull position. The movable clevis is connected to two pull rods extending through the flange plate. The pull rods extend through two guide bushings and an asbestos sealing gland. Above the flange plate the pull rods are connected to a pull-bar

actuator. The hydraulic ram at each position is connected to the respective pull-bar actuator through a load-cell coupling. The stationary clevis is secured to the base plate with 0.75-in. stainless-steel (NAS1012-15) bolts. The base plate is, in turn, secured to compression members to transmit loading to the ram mounting structure (see Fig. 2-3).

2.2.2 Liquid-Hydrogen Dewar

The cylindrical dewar (Ref. AGC Drawing 090683) is composed of two concentric cylinders, with similar 2:1 elliptical closures, connected to a common circular top plate (Fig. 2-4). A vacuum is maintained between the cylindrical vessels for insulation. A relief valve is provided for the vacuum chamber. The inner vessel contains the cryogen can, which is filled with LH_2 during operation. The cryogen can is secured to the underside of the pulling assembly flange plate. The evaporated cryogen is discharged over the top edges of the cryogen can and from the bottom of the dewar cavity through a 1.25-in. exhaust line.

The dewar is secured to the test-assembly flange plate with twenty 0.50-in. bolts and sealed with an 0.0625-in.-thick asbestos gasket. The bolts are of A286 specification. They are an external-wrenching type with allowables in tension of 140,000 psi minimum at room temperature. When the system is assembled, the test assembly is eccentric to the dewar centerline by approximately 5 in.

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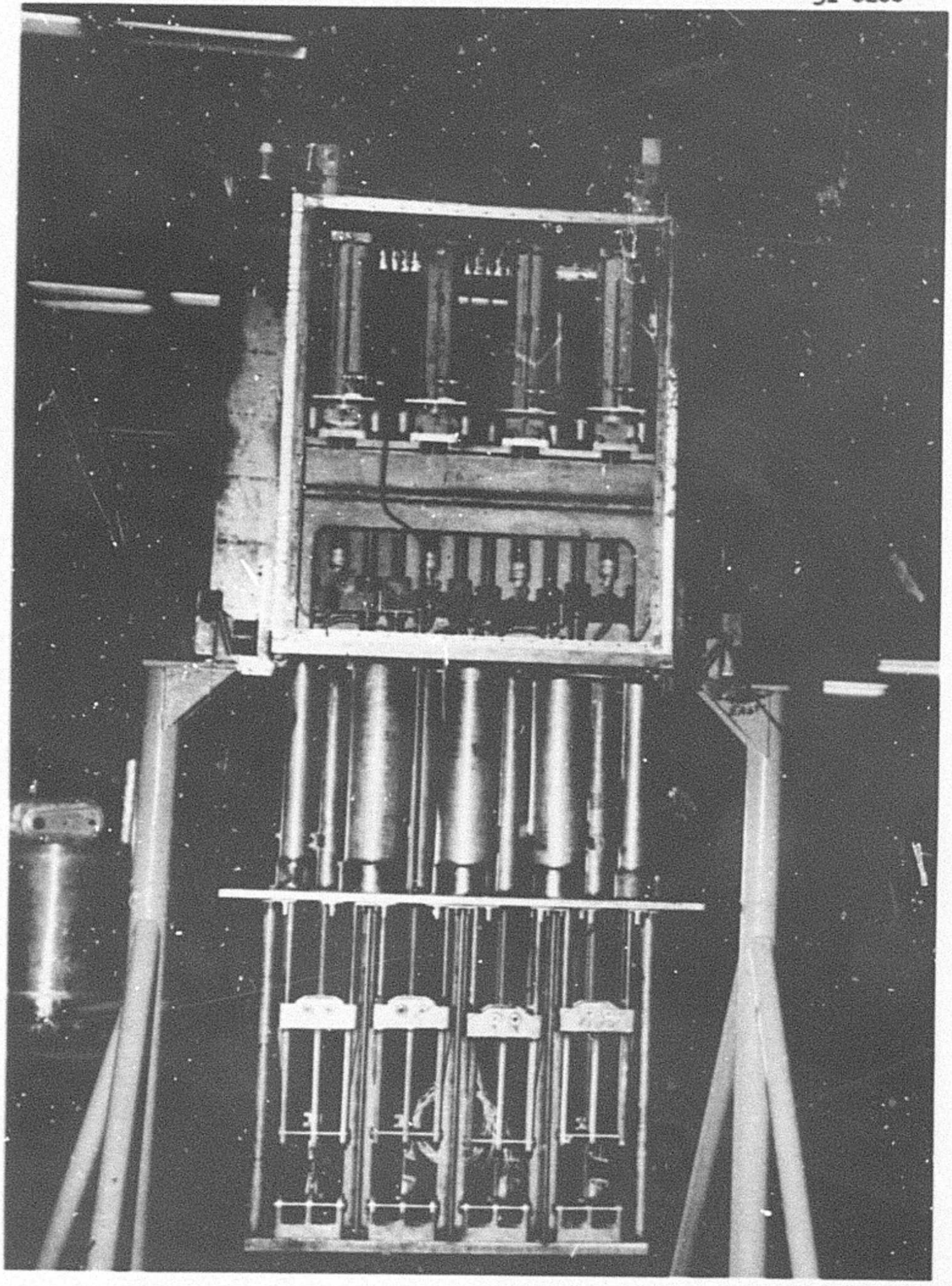

Figure 2-3 AGC Cryogenic Materials Test Assembly (Reactor Side)

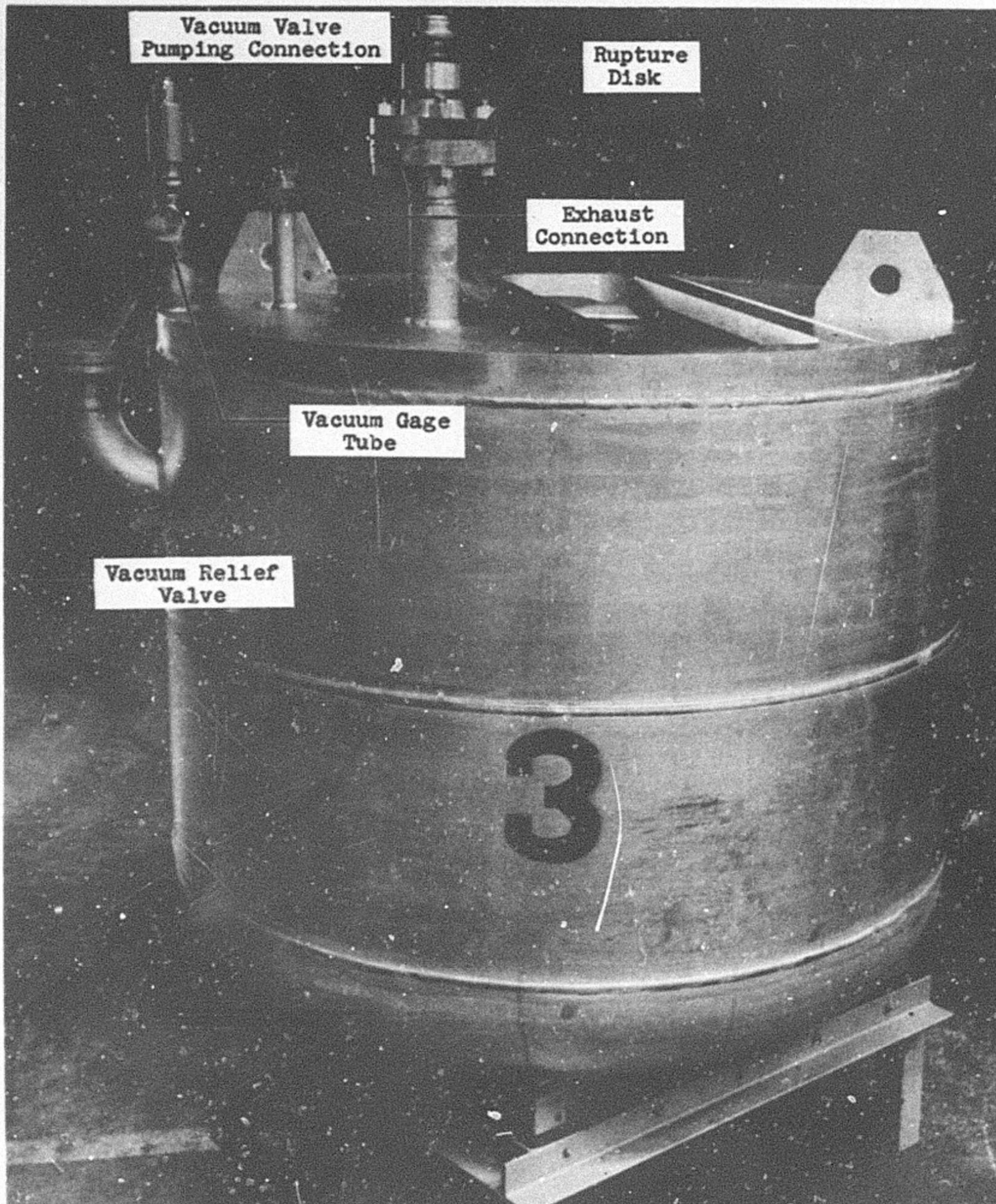

Figure 2-4 Dewar for AGC Cryogenic Materials Test Assembly

Specifications and structural analyses of the dewars are contained in References 7 and 8, respectively.

2.2.3 Equipment Safety Provisions

Safety provisions for all test equipment are listed as follows:

1. The entire upper portion of each test assembly is enclosed in a shroud. All access fittings or lines are routed into or through the shroud for termination or connections. The shrouds are continuously purged with GHe at approximately 2 cfm to maintain an inert atmosphere. The shroud exhaust is routed through a 1.25-in. swing check valve at the top of the shroud and vented out of the pool to a vent stack at the north end of the facility. The shroud vent lines are 1.5-in. stainless-steel flex lines and are paralleled into the 3-in. vent system.

2. A pop safety valve is incorporated as overpressure protection for each test assembly and is set at 7.5 psi. The valve is positioned in and vented into the shroud. The valve is equipped with a hermetic microswitch to give an indication of actuation. Both a visual and audible alarm are set off in the control room upon actuation. The valve is connected to the dewar by a 1.25-in. stainless-steel tube flanged at the shroud and welded at the assembly mounting flange. In case the valve should actuate, the shroud exhaust is sized sufficiently to handle the normal boil-off.

3. A 2.00-in., 22-psi rupture disc is incorporated in the dewar upper closure. The rupture disc is ported to the shroud exhaust system for venting out of the pool.

4. The normal exhaust is vented from the dewar to a burn stack. The exhaust fitting at the dewar and the rupture disc are enclosed in an inert shroud. The shroud is purged continuously with GHe at approximately 2 cfm. The dewar-shroud exhaust is vented into the pull-assembly shroud system.

5. Liquid hydrogen is supplied to each dewar through a 3/4-in., vacuum-insulated, flexible supply line. The termination at the test assembly is made inside the shroud. A rigid, vacuum-insulated, stainless line is routed out of the shroud and welded into the mounting flange.

6. The electrical wiring required for liquid-level indication and temperature-monitoring thermocouples is routed out of the dewar through a 2-in. stainless tube. The tube is welded at the mounting flange and bolted with an asbestos seal at the shroud. The wiring is terminated at the shroud in a hermetic connector. This wiring, plus additional instrumentation and control parameter wiring, is routed out of the shroud through hermetic connectors.

7. Dewar pressure and shroud pressure are monitored continuously throughout the test. IRC 0-15-psig transducers are utilized as pressure transmitters. The output signal of each transducer is continuously recorded on a strip recorder in the control room (see Fig. 2-5). The transducers are mounted in the handling area and connected to the dewar and shroud with 50 ft of 0.25-in. copper tubing. The line to the dewar is routed through the shroud with a connection made inside the shroud.

2.2.4 <u>Hydraulic System</u>

Load application to the tensile and shear specimens is by means of hydraulic rams. Each basic system has the following components:

1. A master cylinder (secured between the movable crosshead and the load cell of the Instron tensile-test machine (see Fig. 2-6).

2. Four slave (or pulling) cylinders located on each assembly.

3. Pressure and return manifold gages.

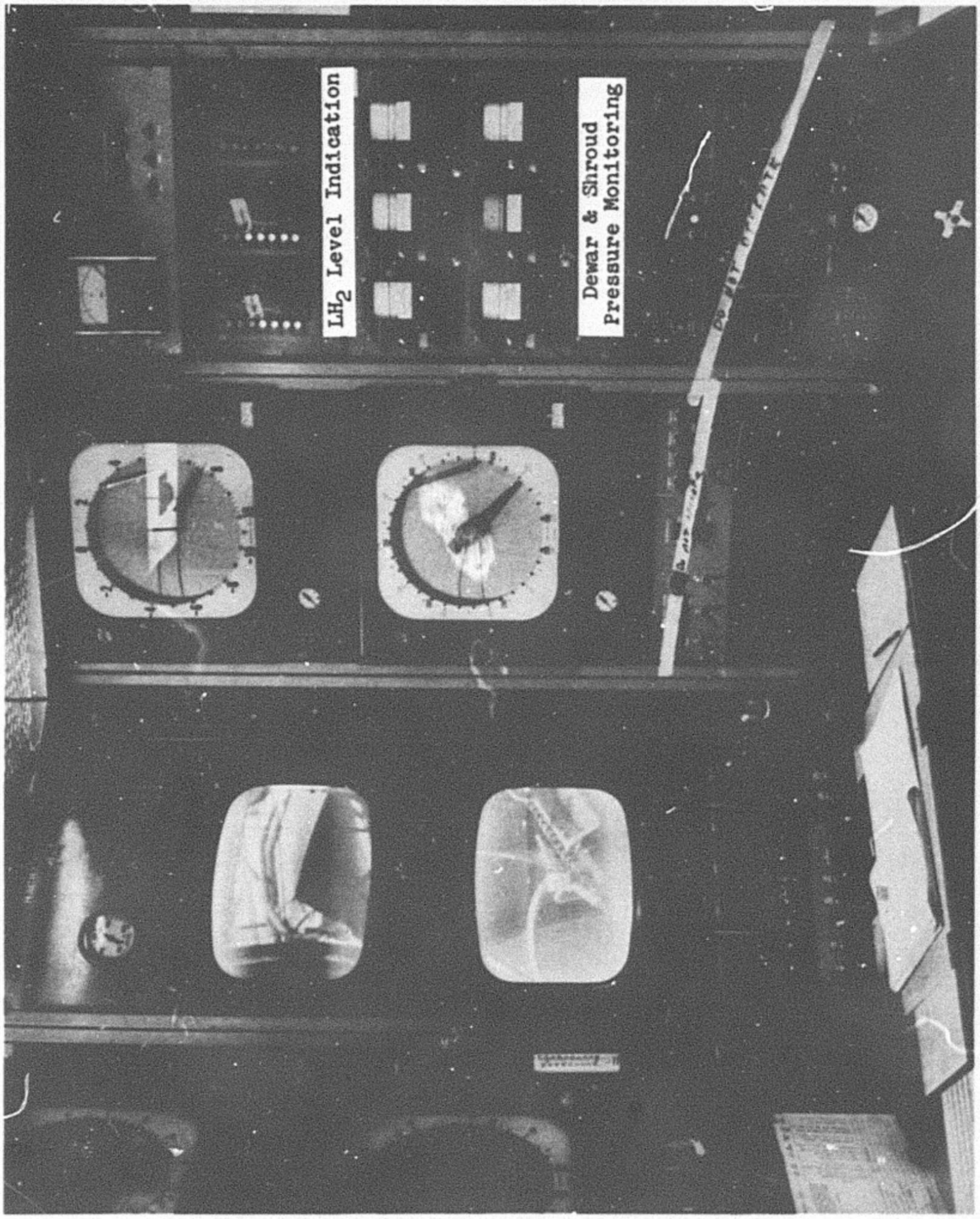

Figure 2-5 Radiation Effects Console in Reactor Control Room: Right Side

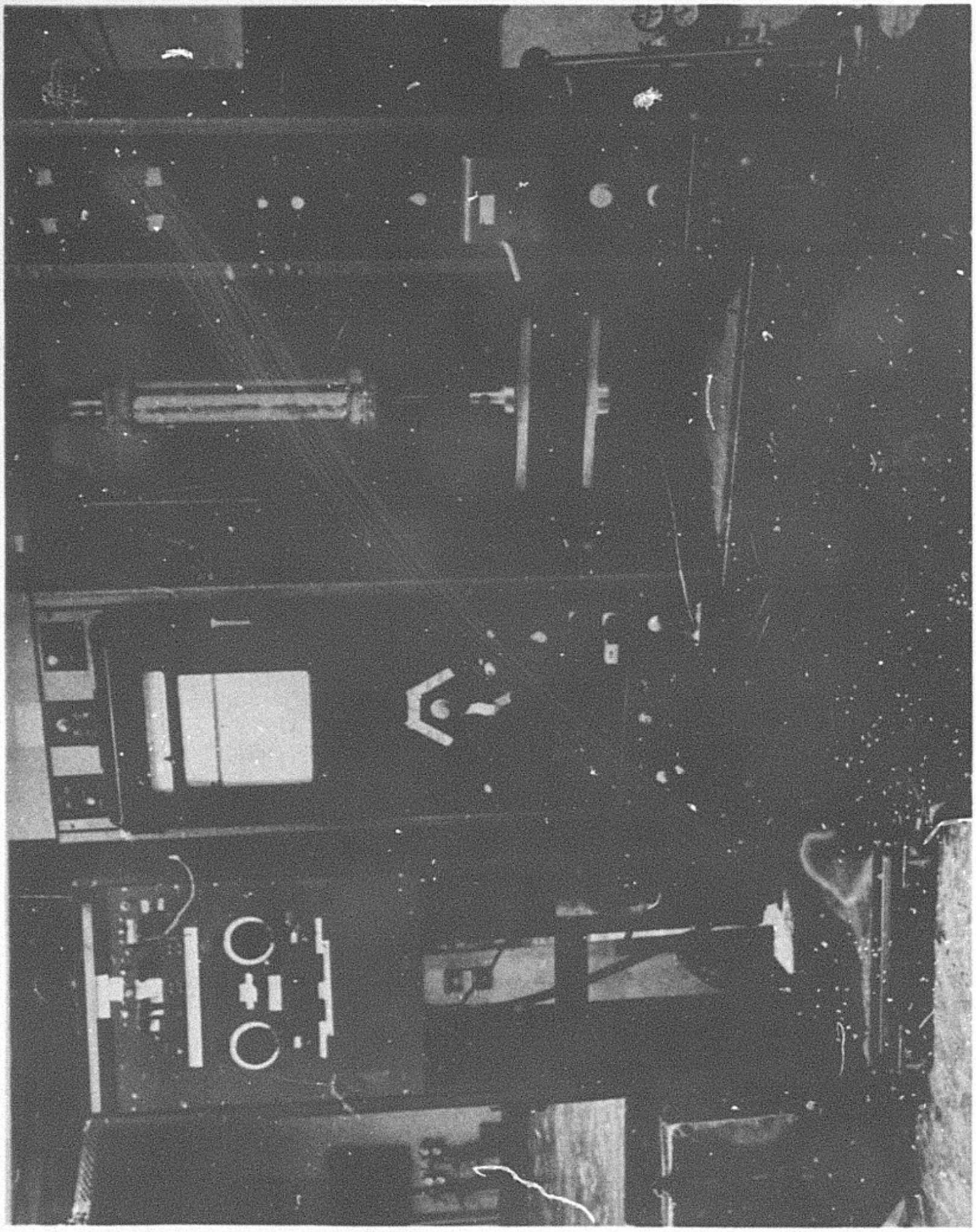

Figure 2-6 Instron Tensile Test Machine with Master Cylinder Installed

4. Make-up and bleed reservoir.

5. Supply reservoir and pressure pump.

6. Interconnecting lines, valves, and fittings.

Each cylinder has a bore of 3.25 in., a stroke of 14 in., and a rod diameter of 1.375 in. This gives an effective rod-end piston area of 6.8 sq. in. The lines are connected to the cylinders to permit pressure application to the rod end. Bleed fittings were recently added to the rams to permit bleeding the rams with specimens installed.

2.2.5 <u>Cryogenic Transfer System</u>

Liquid hydrogen is supplied to each test assembly from an LH_2 transfer trailer located adjacent to the reactor pool. An LH_2 supply manifold, equipped with remotely operated supply valves, is located outside the facility shield. Each supply valve is equipped with a pneumatically controlled positioner to permit proportional control of the LH_2 flow. Each test assembly is connected to the manifold with 90 ft (in two sections) of nominal 0.75-in.-ID, vacuum-insulated, flexible lines. The manifold is equipped with two inlet valves to permit change-over of the LH_2 trailers without interrupting flow to the test assemblies.

2.2.6 <u>Cryogenic Exhaust System</u>

Liquid hydrogen is contained in a can inside of, and open to, the main dewar cavity. The evaporated cryogen is exhausted through

a 1.50-in. line ported from the bottom of the dewar cavity. The exhaust is ported through a combination of flexible and rigid 1.50-in. lines to a point outside the facility shield. Each 1.50-in. line is routed through a gate valve and check valve into a common 5-in. line. The 5-in. line ties into the burn stack. The exhaust system is equipped to vacuum-purge the test assemblies.

The vacuum-purge system is composed of a valve network, a mechanical vacuum gage, a compound pressure-vacuum gage, and a vacuum pump. The valves are 1.50-in. unrestricted gate valves for vacuum and/or cryogenic service. The vacuum pump is a Kinney KD-30 pump rated at 30 cfm pumping speed with an optimum capability of 10 microns. The pump and motor are class "B" explosion-proof and are equipped with Lox-Safe oil. The system is designed to purge either an individual segment or all segments in parallel.

2.2.7 Cryogenic Level System

A liquid-level indication system is provided to continuously monitor the liquid level in the test assemblies. The method incorporated is that of point level sensors. The system consists of a sensor probe and an indication panel. The panel is presented in Figure 2-5 and the probe can be seen in Figure 2-1. The probe consists of seven 0.25-watt carbon resistors mounted in a rake and spaced as follows:

No. 1 29.50 in. from the dewar flange

No. 2 21.75 in. from the dewar flange

No. 3 19.00 in. from the dewar flange

No. 4 11.00 in. from the dewar flange

No. 5 9.00 in. from the dewar flange

No. 6 6.25 in. from the dewar flange

No. 7 4.12 in. from the dewar flange

The optimum control level is between points No. 4 and No. 5.

Each resistor in the probe is excited to dissipate its rated power for maximum sensitivity and response. The large difference in the heat-transfer rate of a sensor when it is in liquid and when it is in vapor produces a temperature and corresponding resistance change in the sensing element. As this resistance reaches a threshold value, it activates an output signal in the transistorized control panel. This signal triggers an indication light and/or alarm system.

The liquid-level control system is utilized to maintain a near constant level in each test assembly. A Bristol control unit, with a +100° to -430°F range kit, is used as the controlling device (see Fig. 2-7). A copper-constantan thermocouple is positioned in the dewar relative to the desired control level. The thermocouple EMF is converted to a proportional pneumatic signal in the Bristol controller. This pneumatic signal is fed

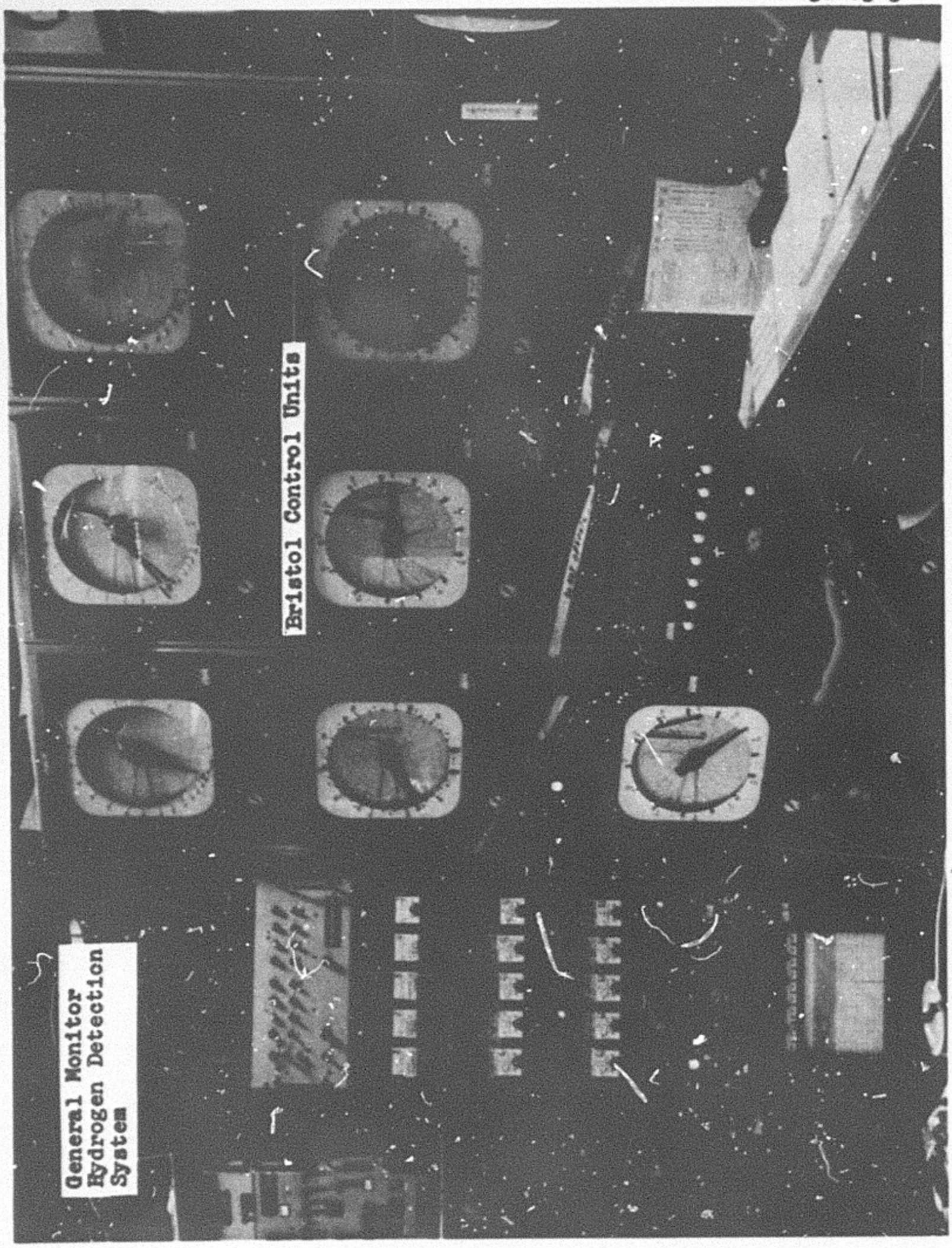

Figure 2-7 Radiation Effects Console in Reactor Control Room: Left Side

to the Fisher proportional positioner, which is an integral part of the cryogen manifold and connected so as to control the outlet valve.

2.2.8 Instrumentation

Applied Load Measurement. The applied load to each specimen is measured by a four-arm strain-gage load cell and recorded on a Sanborn millivolt recorder. (The load cells can be seen in Figure 2-8.) The strain gages used are BLH type and were applied with the Rokide process for optimum radiation resistance. Each load cell was calibrated utilizing the Sanborn millivolt recorder for data acquisition. Calibration data were obtained in representative increments up to 10,000 lb (see Fig. 2-9).

Strain Measurement. A mechanism is provided at each pull position to measure the specimen pull-rod displacement. This measurement is continuous for the total rod movement. A Helipot potentiometer (50,000 ohm, 360^{o} rotation) is geared through a rack and pinion to the specimen pull rods. The potentiometers have nine equally spaced taps. Selection of gear ratio and potentiometer tap spacing was made to give 360^{o} of pot rotation per 0.50 in. of rod movement. With the nine-tap pot, this provides full-scale deflection of the recorder for each 0.050 in. of rod movement. This gives a resolution of from 0.5 to 1.0 mil. Each position is calibrated in 0.025-in. increments for 2 in. of

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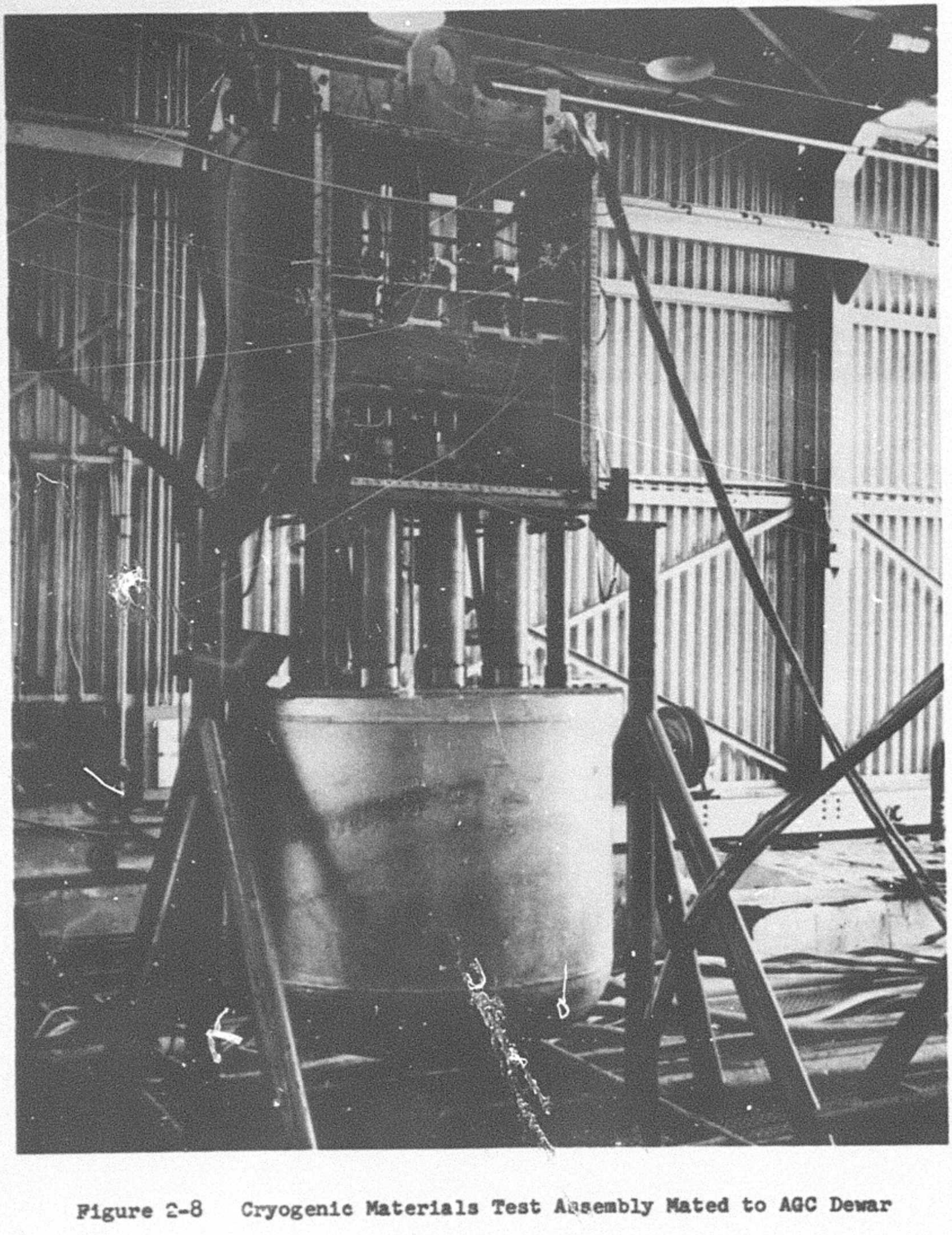

Figure 2-8 Cryogenic Materials Test Assembly Mated to AGC Dewar

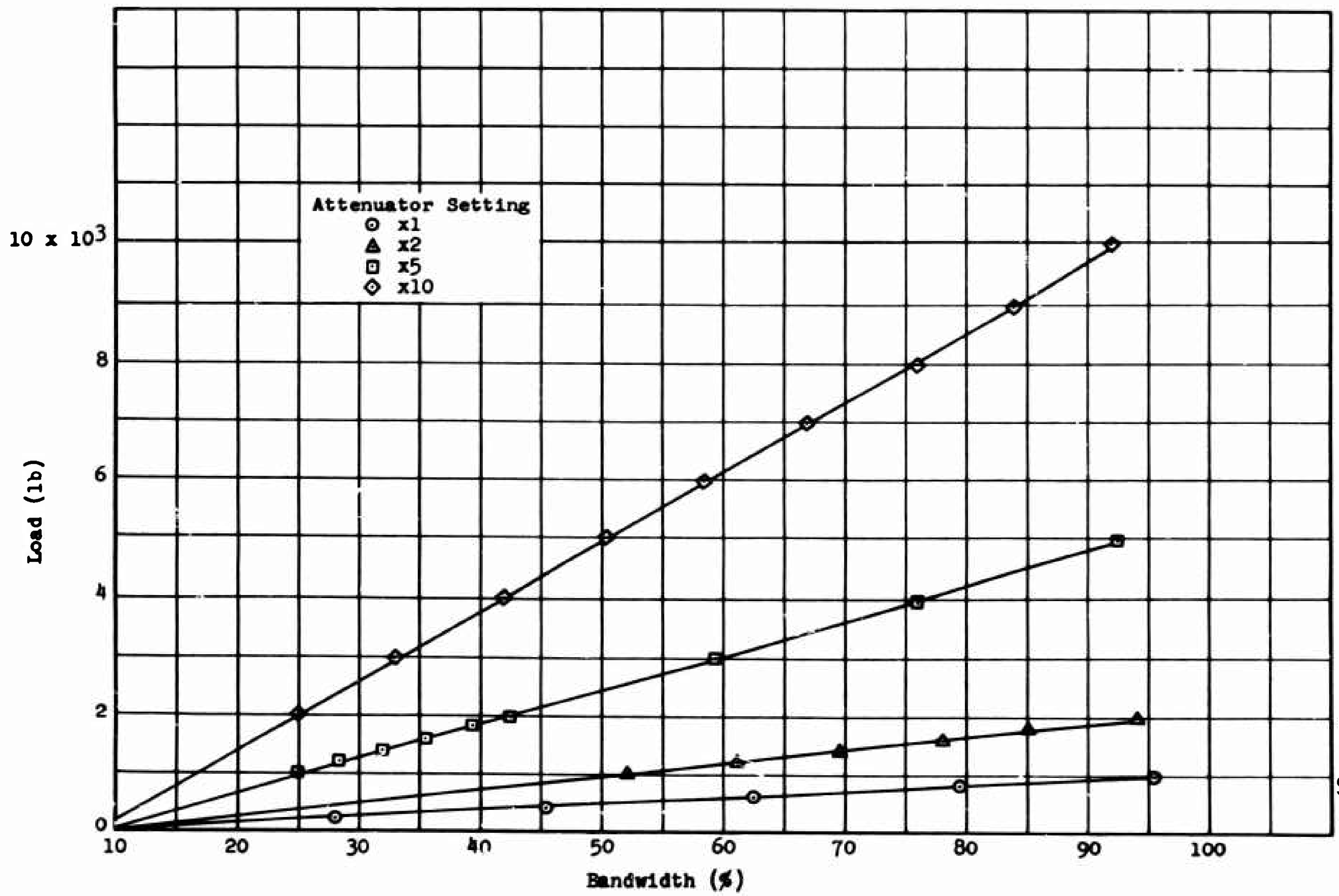

Figure 2-9 Typical Load-Cell Calibration Curves

rod movement (Fig. 2-10). These mechanisms can be seen in Figure 2-8.

An extensometer mechanism is activated at one position of one assembly to measure the strain between the shoulders of a selected group of control specimens. Tabs are secured to the upper and lower shoulders with a 2-in. spacing between. Fingers (or arms) are positioned relative to the tabs and connected to concentric tubes which are in turn connected to a displacement transducer (see Fig. 2-11). The transducer used is a Physical Sciences variable-permeance type with a $\pm$1.000-in. range. The cryogen gas seal around the concentric tubes is effected by a cylinder-and-piston arrangement utilizing Teflon "bal seals." The extensometer mechanism is indexed from one specimen to another by means of a combination hydraulic and pneumatic indexing system. Each extensometer mechanism is calibrated to 0.800 in. in representative progressive increments (see Fig. 2-12).

A 2-in. gage-length clip-on extensometer is used to measure the strain within the elastic region of all specimens tested at ambient temperature. This extensometer has an extremely high resolution with a travel of 0.040 in. The transducer was calibrated in representative increments to the limit of its travel (see Fig. 2-13).

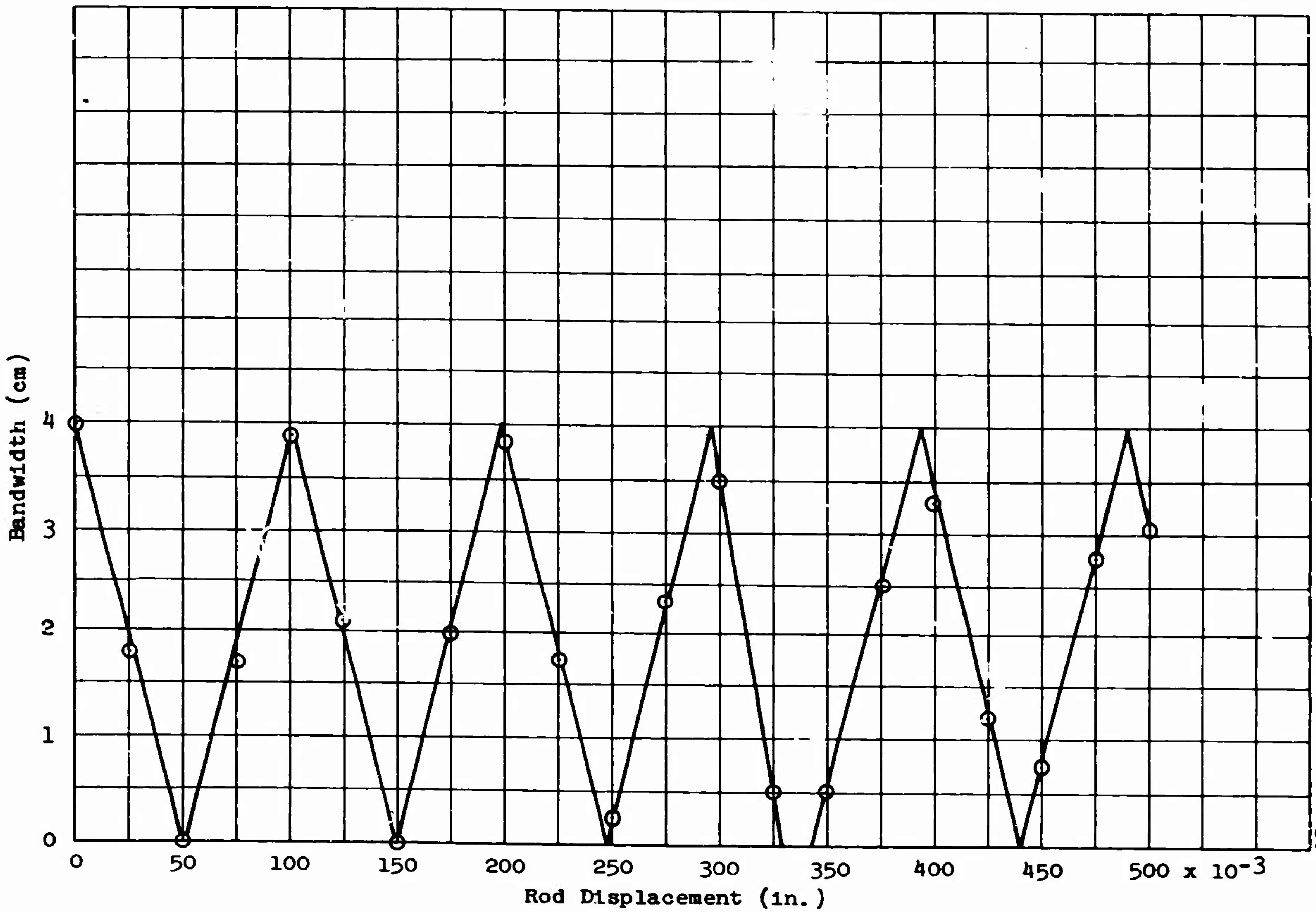

Figure 2-10 Typical Rod-Movement Calibration Curve

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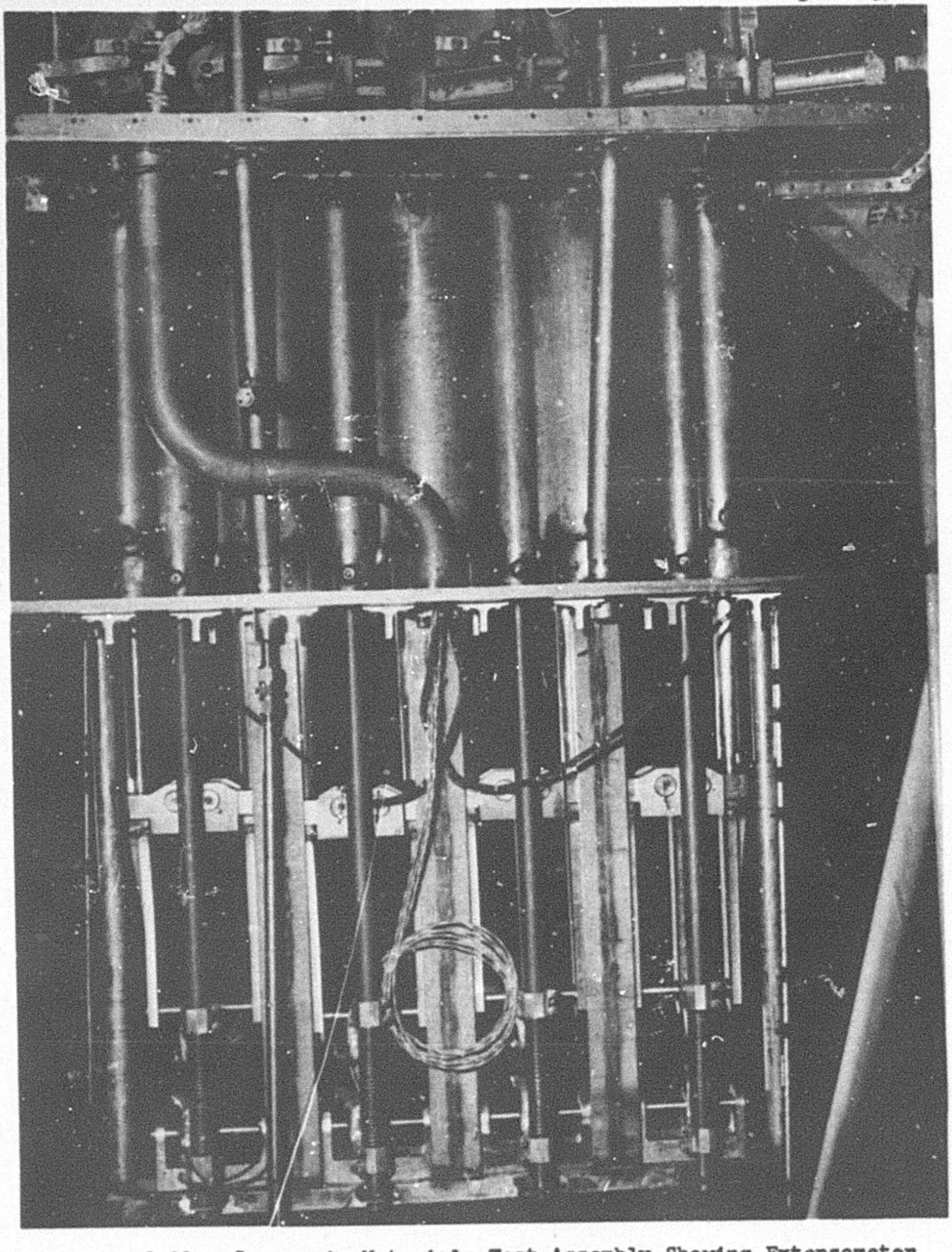

Figure 2-11 Cryogenic Materials Test Assembly Showing Extensometer Mechanisms Installed

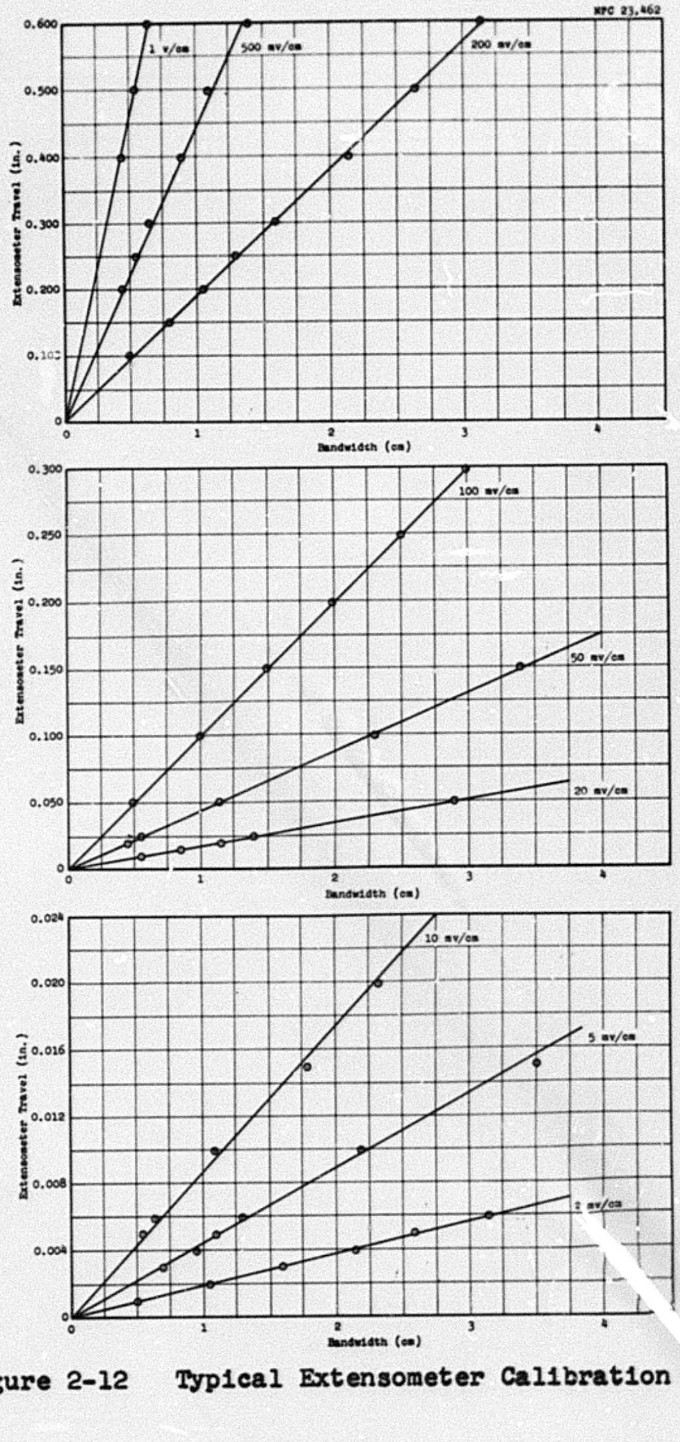

Figure 2-12 Typical Extensometer Calibration Curves

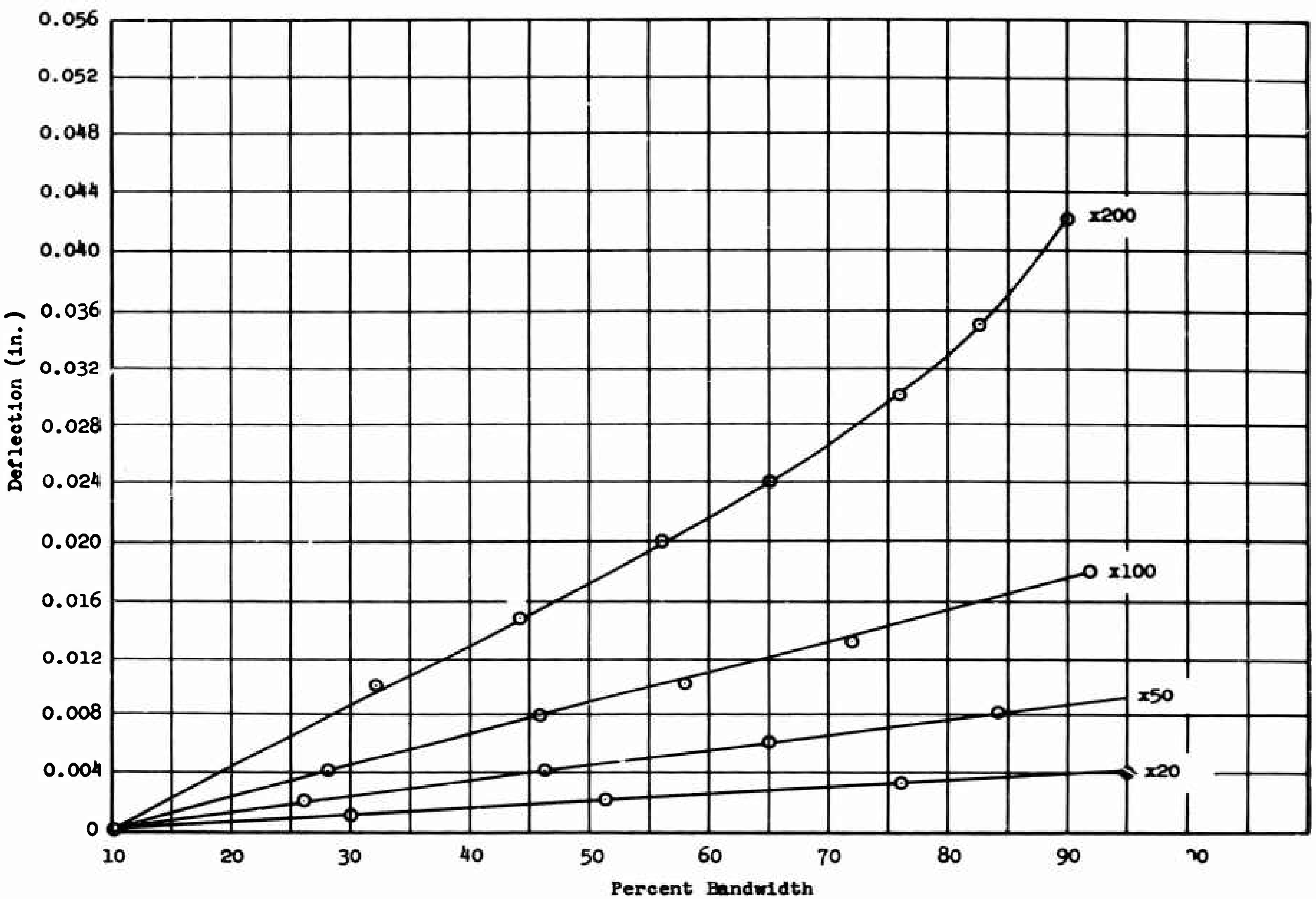

Figure 2-13 Calibration of Room-Temperature Extensometer

Temperature Monitoring. Eight copper-constantan thermocouples are provided in each dewar for monitoring the liquid, vapor, and specimen temperatures.

Four of the thermocouples are provided to measure the temperature of the hydrogen vapor and/or liquid and to supply the signal for the liquid-level control system.

The remaining four thermocouples are provided to measure the temperature of specimens during warmup. The output of these four thermocouples is recorded on a Brown recorder.

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III. ANALYSIS AND DISCUSSION OF RESULTS

In the original test plan, the three different exposure levels were to be achieved in one 25-hr, 3-Mw irradiation by varying the spacing between the test assembly and the reactor and by shielding. However, during the thermal-cycling operation prior to irradiation, one of the LH_2 transfer lines was found to be damaged and not immediately repairable. Because of this, the low-dose irradiation was delayed, but the assemblies receiving the high and intermediate doses were irradiated as planned (25 hr at 3 Mw) in the north and east positions, respectively. The specimens were tested at the first two environmental conditions and the equipment was then removed from the test cell.

To achieve the low-dose exposure, the assembly was placed in the north position and irradiated for 1 hr at 3 Mw. The specimens were then tested and the equipment removed from the test cell. Typical fractured specimens at the different dose levels can be seen in Figures 3-1, 3-2, and 3-3. The remainder of the testing was satisfactorily accomplished in accordance with the test plan.

3.1 Correction and Correlation of Data

The specimens tested at ambient temperature were pulled to fracture in the Instron tensile test machine. The strain

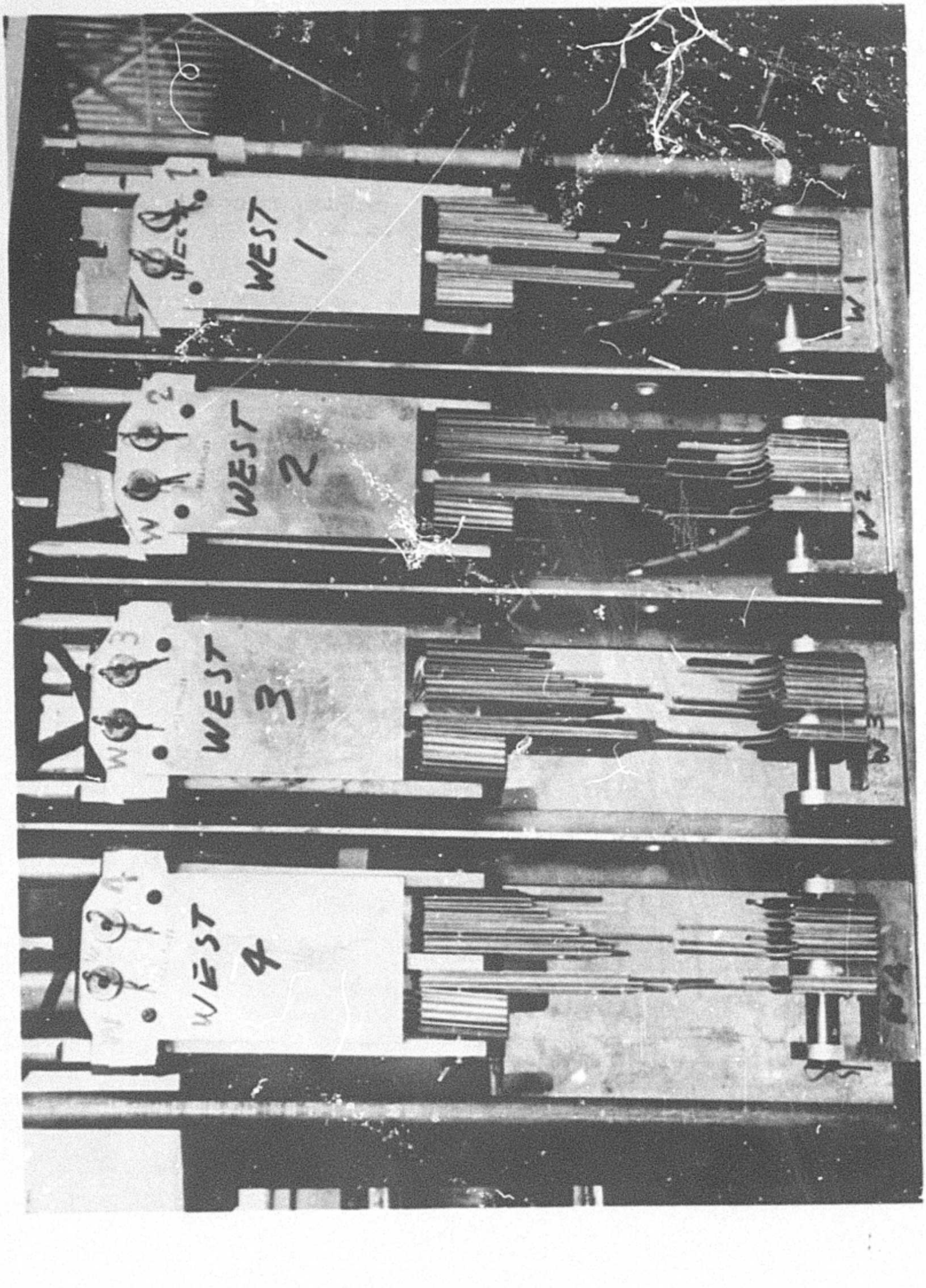

Figure 3-1 Fractured Specimens Tested after Low-Dose Exposure

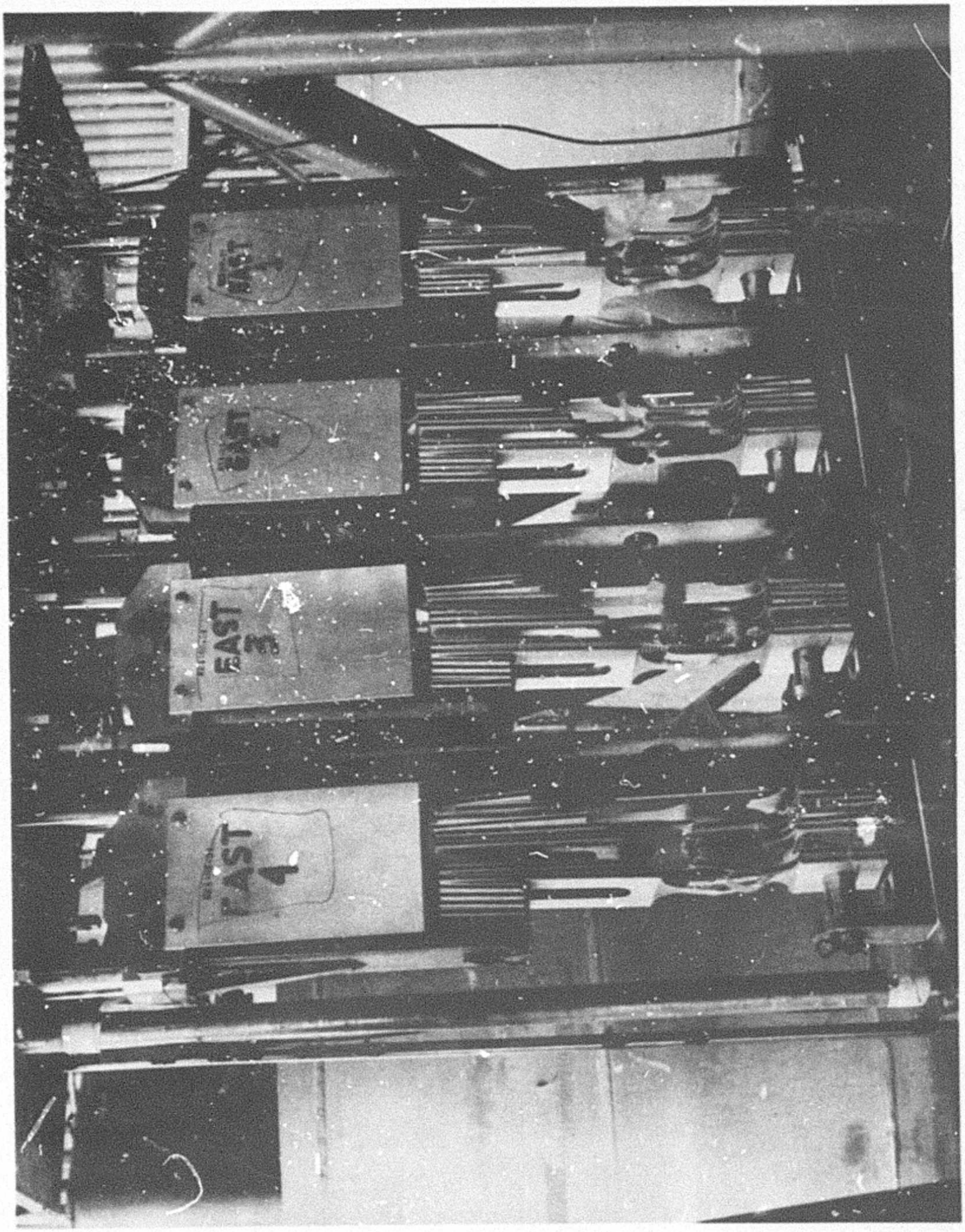

Figure 3-2 Fractured Specimens Tested after Intermediate-Dose Exposure

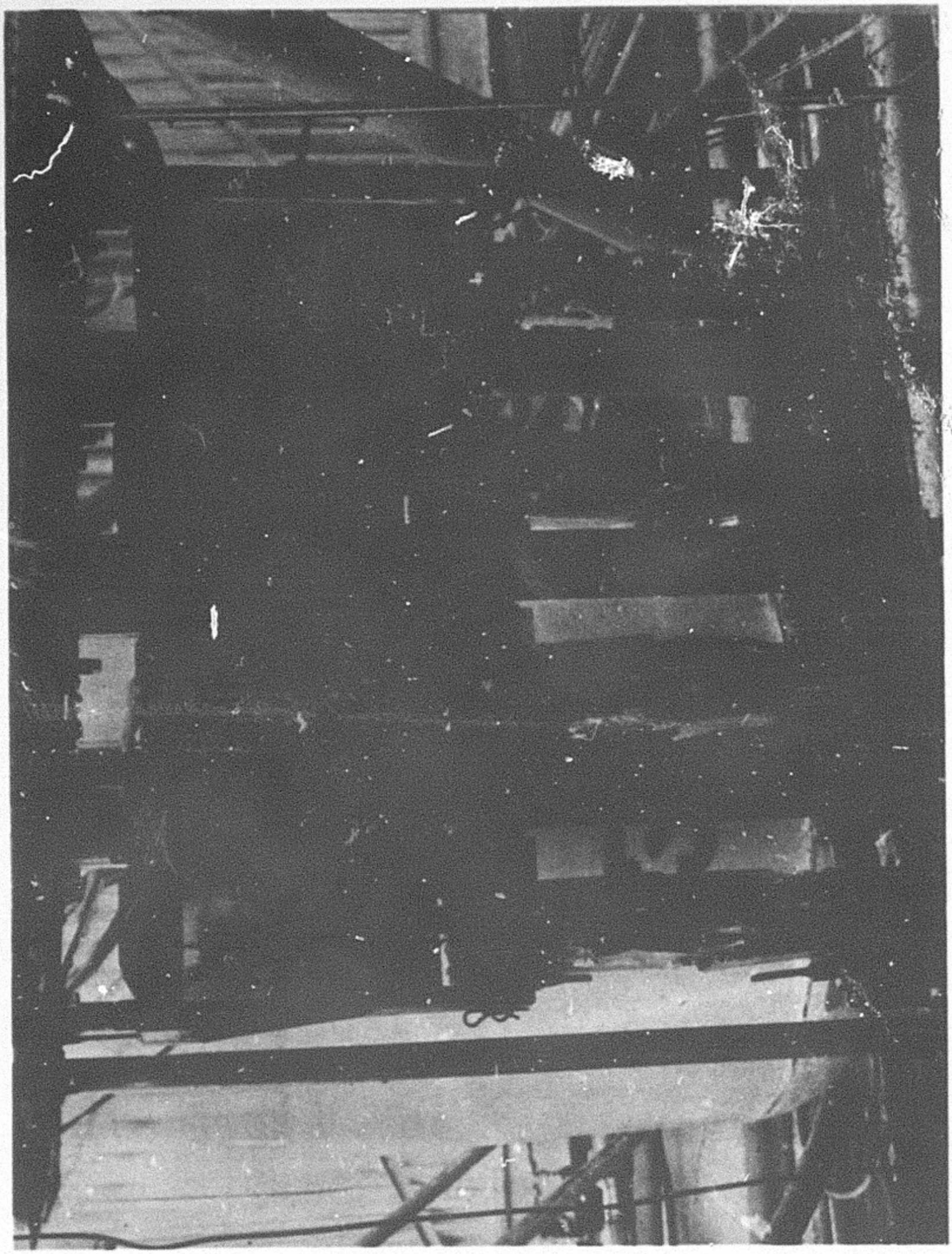

Figure 3-3 Fractured Specimens Tested after High-Dose Exposure

for all materials, with the exception of Teflon, was measured by a 2-in. gage-length clip-on extensometer. The strain recorded when testing the three types of Armalon material was always within the operating range of the extensometer. However, some extrapolation was necessary with the strain data recorded from testing of the Superpolymer SP-3 specimens, and because of the extremely high elongation of Teflon, crosshead travel was used as an indication of strain for this material.

The specimens tested at LH_2 temperature were pulled to fracture in the remotely operated cryogenic tensile test assemblies described in Section II. The load cells functioned completely satisfactorily and no correction of stress data was required. The strain was measured by the rod-movement mechanisms. These devices measure not just the strain that occurs within the gage length, but the total, or gross, strain that occurs in the system. For this reason, it was necessary to consider two correction factors to determine the approximate true strain that occurred within the reduced cross section of the specimens. These two strain correction factors were applied to the data from all specimens tested at LH_2 temperature.

3.1.1 System Error

As previously mentioned, the rod-movement mechanism measures the total, or gross, strain that occurs in the

complete pull-rod train. To eliminate the deflection that occurred outside the specimen, the following correlation was made.

Extensometer tabs were attached to the upper and lower grip sections of 12 specimens (all materials except SP-3). These specimens were tested in LH_2 using the same equipment and instrumentation previously used for the irradiated and control specimens. One extensometer mechanism, described in Section 2.2.8, was activated and used in the testing of these 12 specimens. This mechanism measures, essentially, the strain that occurs between the specimen shoulders. Average stress-strain curves, drawn from both rod-movement and extensometer strain-measurement values, are shown for the four materials in Figures 3-4, 3-5, 3-6, and 3-7. A gage-length of 2 in. was assumed for presentation of these curves. From a comparison of these four sets of curves, it can be seen that the strain ratio of extensometer data to rod-movement data is reasonably linear and consistent. All four materials were considered separately, and the combined average ratio (a) was found to be 0.665. A typical plot of the ratio for one of the materials is shown in Figure 3-8. The rod-movement strain data were multiplied by 0.665 to eliminate the system error. This correlation was used for all materials.

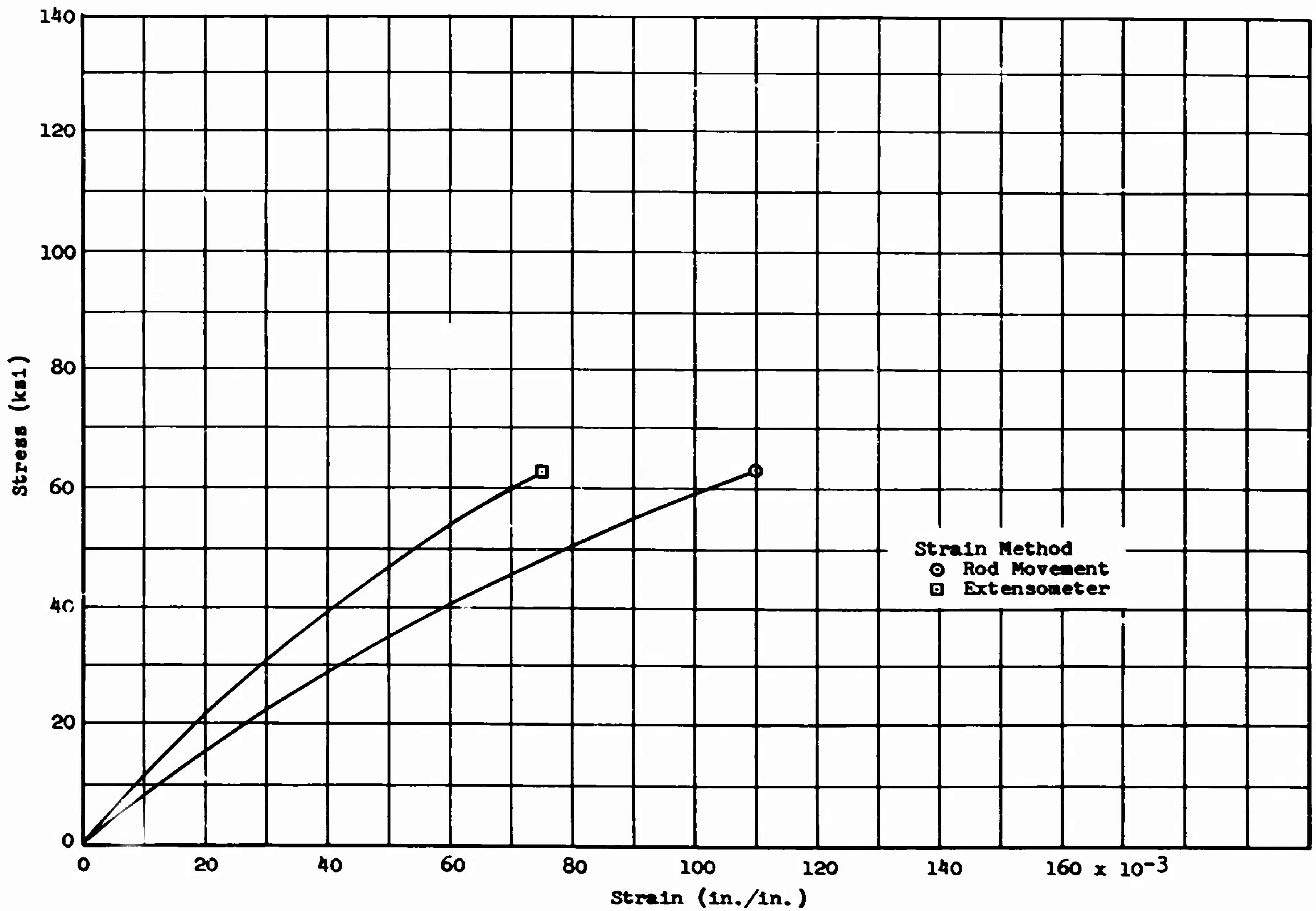

Figure 3-4 Average Stress-Strain Curves Showing Relationship Between Two Strain-Measurement Methods: Armalon 405-CL-116

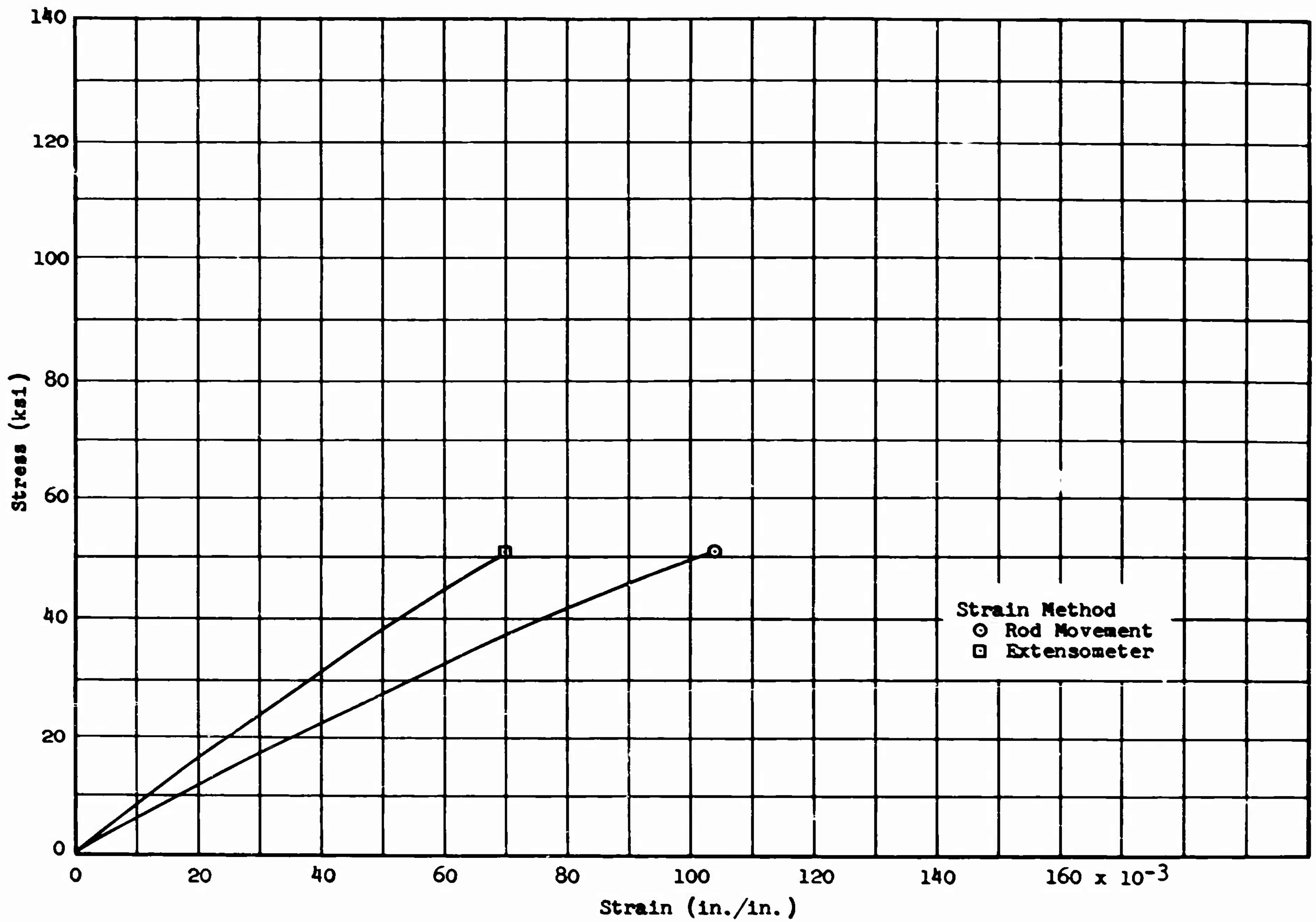

Figure 3-5 Average Stress-Strain Curves Showing Relationship Between Two Strain-Measurement Methods: Armalon 510-L-112

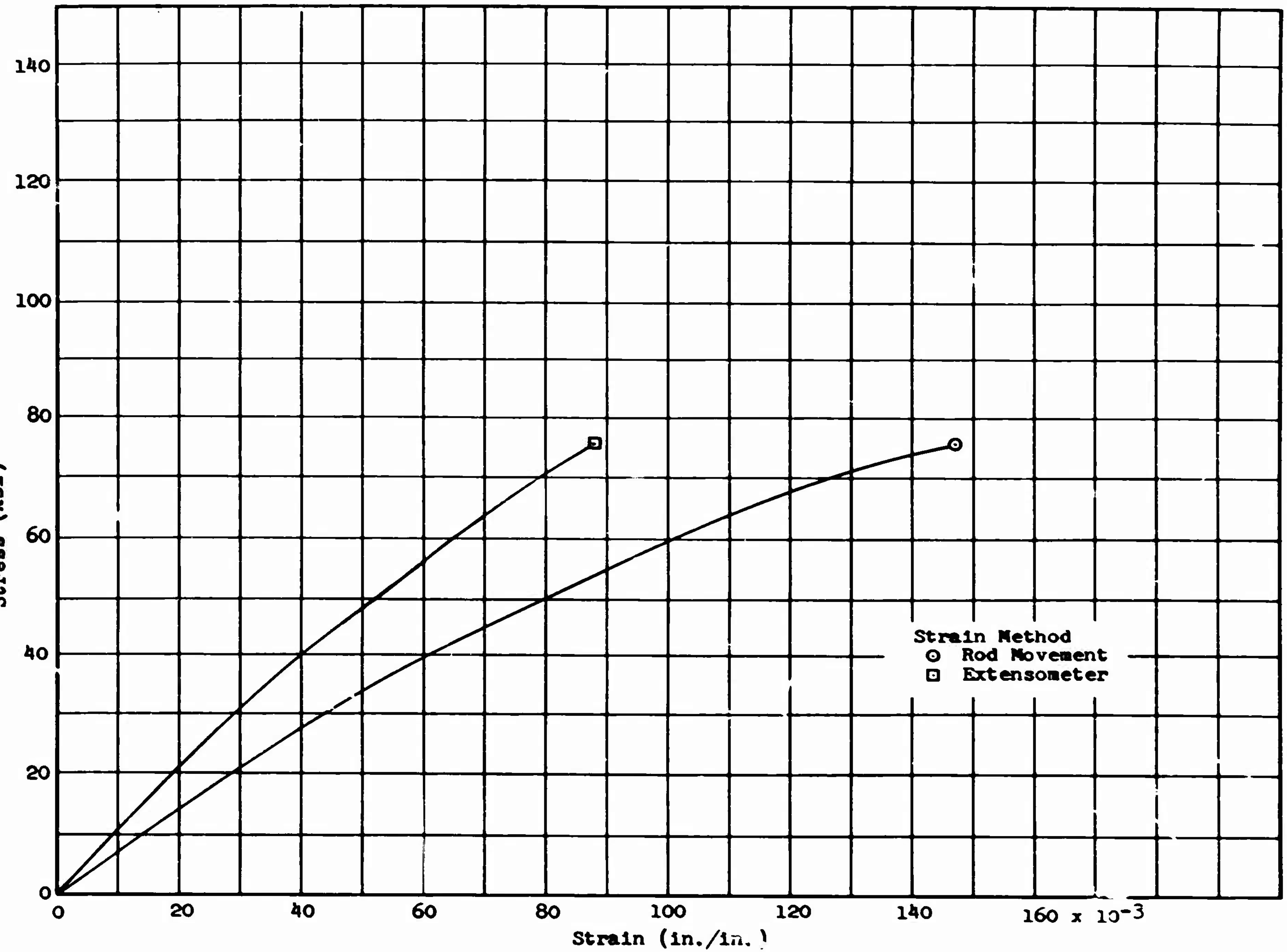

Figure 3-6 Average Stress-Strain Curves Showing Relationship Between Two Strain-Measurement Methods: Armalon 510-L-128

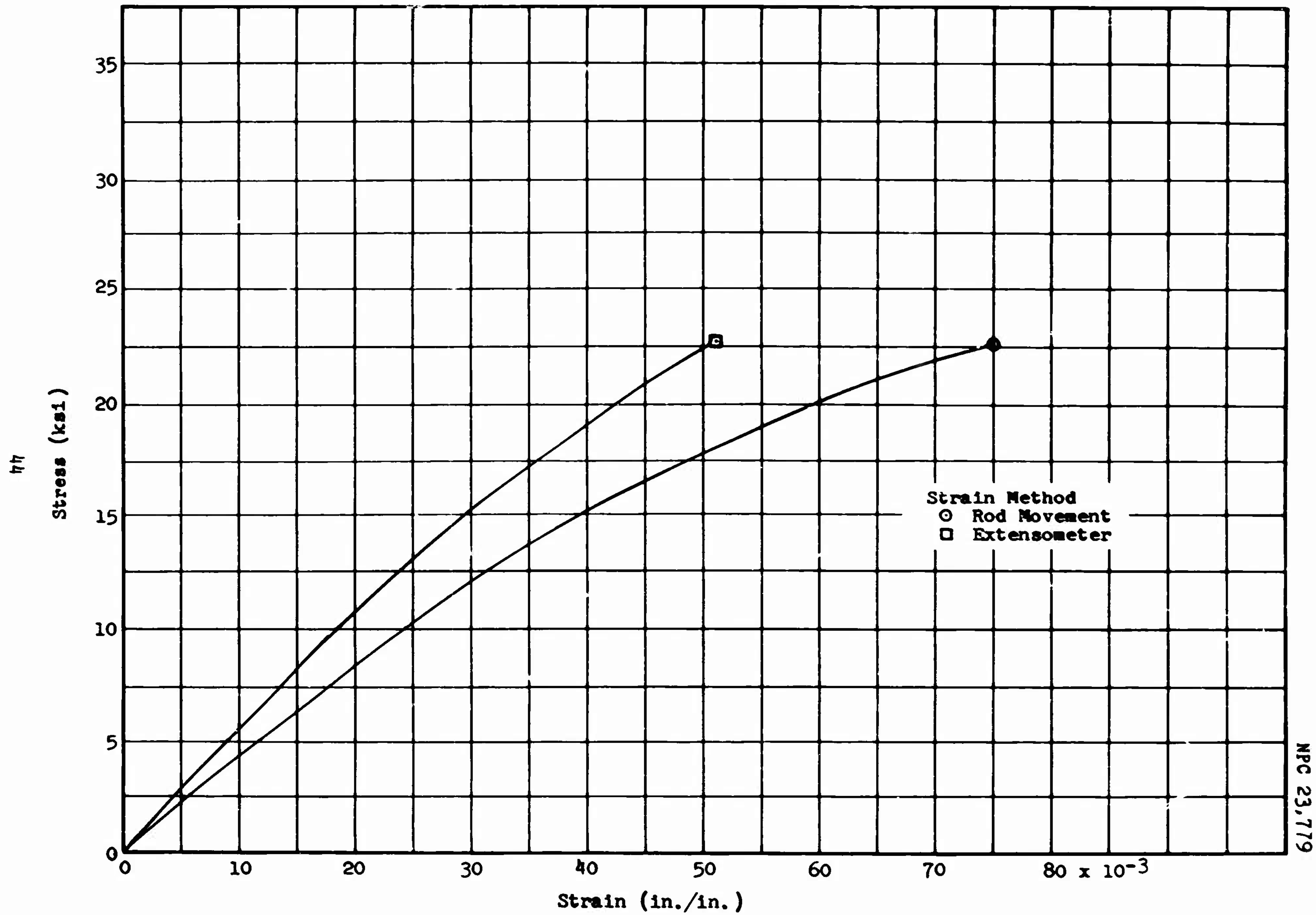

Figure 3-7 Average Stress-Strain Curves Showing Relationship Between Two Strain-Measurement Methods: Teflon FEP

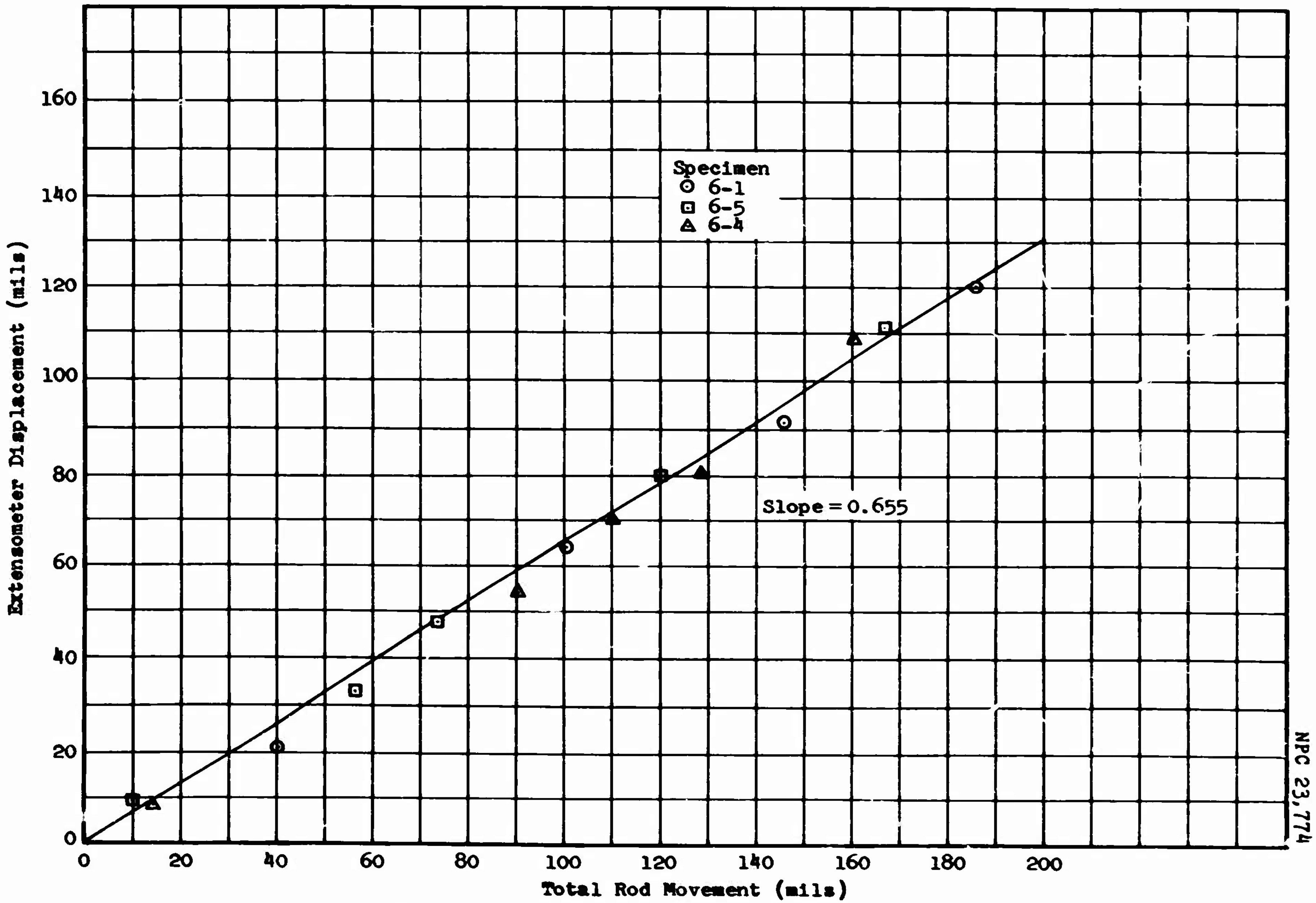

Figure 3-8 Strain Ratio of Extensometer Method to Rod-Movement Method for Armalon 405-CL-116

3.1.2 Gage-Length Correction Factor

The previous section explains the method used to correct for measured strain that occurs outside the specimen. This section describes the method used to correct for strain that occurs within the specimen but outside the reduced cross section. The greater portion of this strain error occurs in the specimen between the point of tangency at the reduced cross section and the shoulder at each end. This error is significant and must be eliminated to find the approximate true strain within the 2-in. gage-length section.

A relationship can be determined for specimens of a given configuration by considering the specimen geometry. A complete and detailed explanation of the mathematical mechanics for determination of this factor is presented in Appendix B of Reference 3. In GTR Test 17, specimens of two basic configurations were used, necessitating two sets of calculations:

1. The three Armalon materials and Teflon specimens were fabricated from 0.125-in. sheet with 0.0625-in. aluminum doublers bonded and riveted to each side of the grip sections. The correction factor for this configuration (b_1) was found to be 0.6283.

2. The Superpolymer specimens were machined to a 0.125- by 0.500-in. reduced cross section from 0.25-in. sheet stock. The correction factor for this configuration (b_2) was found to be 0.6539.

3.1.3 Combined Correction Factors

Considering the correction factors explained in the two previous sections, it is now possible to express or present, for any of the materials tested in LH_2, the approximate true strain in terms of total rod movement at any load condition.

Given the following definitions:

ϵ_1 = approximate true unit strain for Armalon 405-CL-116, 405-L-112, and 510-L-128 and for Teflon FEP;

ϵ_2 = approximate true unit strain for Superpolymer SP-3;

C_1 = combined correction factor for Armalon and Teflon;

C_2 = combined correction factor for Superpolymer SP-3;

RM = total rod movement;

GL = gage length (2 in.);

a = system error correction factor (0.665);

b_1 = gage-length correction factor for Armalon and Teflon specimens (0.6283);

b_2 = gage-length correction factor for Superpolymer specimens (0.6539);

the approximate true strain may be found as follows:

$$\epsilon_1 = (RM/GL)\cdot C_1, \text{ where } C_1 = ab_1$$

$$= 0.2089\cdot(RM);$$

$$\epsilon_2 = (RM/GL)\cdot C_2, \text{ where } C_2 = ab_2$$

$$= 0.2174\cdot(RM).$$

3.2 Presentation of Property Data

All irradiation specimens were submerged in LH_2 during the irradiation period, then tested at the five different environmental conditions. Control specimens were tested at environmental conditions nearly parallel to those of the irradiation specimens. A description of these conditions is given in Section 2.1.1. This section presents and discusses the mechanical-property and x-ray diffraction (physical-property) data.

The mechanical property data are presented in several forms; stress-strain curves, averaged-data plots of ultimate tensile strength and ultimate strain, and tabulated detail data. All data in this section are categorized by material and are tabulated in accordance with dose and environmental condition.

X-ray diffraction studies were accomplished on a selected number of specimens - one specimen from each dose level (including Control) of five materials at environmental conditions 1, 2, and 3. All samples for analysis were taken from the reduced cross section of the specimens, with the exception of the high-dose Armalon specimens, in which case the samples were taken from the grip areas. These studies indicated that there was no significant change in the crystal structure from either dose or environmental condition for any of the materials tested. A representative set of the x-ray traces is shown for each material tested at environmental condition 1.

3.2.1
Armalon TFE-405-CL-116

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3.2.1 Armalon TFE-405-CL-116

This material was tested without difficulty at all test conditions. In general, the specimens of this material did not fail within the 2-in. gage length but fractured at approximately the point of tangency of the reduced section. This was true of the specimens tested at both room and LH2 temperatures. This can be seen in Figures 3-9 and 3-10.

A comparison of the ultimate tensile strength at the different dose and environmental conditions is presented in Figure 3-11. From these data it can be seen that a high degree of damage was detected in the specimens subjected to the high dose and tested at LH_2 temperature. A possible temperature effect is also noted in the control and low-dose specimens. The specimens tested at room temperature exhibited a gradual decrease in strength with an increase in dose.

A comparison of ultimate strain at the different dose and environmental conditions is presented in Figure 3-12. These data indicate a trend similar to the ultimate-stress data for specimens tested at LH_2 temperature. For those specimens tested at room temperature, there is very little or no radiation-induced strain variation.

A tabulation of all detailed mechanical-property data is presented in Table 3-1. A statistical analysis of these

data is included in Section 3.3.

Average stress-strain relationships are presented in Figures 3-13 through 3-17, showing the effects of dose level on specimens tested at environmental conditions 1 through 5, respectively. The stress-strain curves showing a comparison of control specimens tested at conditions 4 and 6 are shown in Figure 3-18; there appears to be a definite decrease in ultimate strain with thermal cycling but no effect on ultimate stress.

The x-ray diffraction studies showed no radiation-induced change at any of the conditions. A typical set of x-ray data is shown in Figure 3-19.

Table 3-1

Armalon 405-CL-116: Ultimate Tensile Strength and Elongation

Environmental Sequence	Test Temp	Control				Low Dose				Intermediate Dose				High Dose			
		Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)
Condition 1	LH_2	1-55	43.9	2	3.1	1-45	56.8	2	4.1	1-37	48.2	2	2.9	1-41	19.1	5	1.9
LH_2		1-56	46.1	2	3.0	1-69	49.9	2	4.1	1-61	54.0	2	3.2	1-65	25.0	5	No Data
		1-79	46.3	2	2.9	1-47	58.2	2	3.3	1-39	48.5	2	3.2	1-43	14.5	5	1.8
		1-80	50.8	2	3.4	1-71	51.3	2	3.8	1-63	51.1	2	3.2	1-67	18.4	5	No Data
		Avg/σ:	46.8/3.4		3.1/0.24	Avg/σ:	54.1/4.0		3.8/0.39	Avg/σ:	50.5/2.8		3.1/0.15	Avg/σ:	19.3/5.1		1.85/0.10
Condition 2	LH_2	1-57	61.2	2	3.7	1-46	58.3	2	3.8	1-38	51.2	2	3.3	1-42	22.6	2	2.6
LH_2→GHe→LH_2		1-58	63.7	2	4.7	1-48	60.7	2	4.0	1-40	50.9	2	3.4	1-66	21.8	2	2.6
		1-81	64.5	2	4.9	1-70	51.9	2	3.8	1-62	56.5	2	3.6	1-44	26.8	2	2.4
		1-82	61.4	2	4.6	1-72	50.6	2	3.8	1-64	55.6	2	4.2	1-68	27.6	2	2.7
		Avg/σ:	62.7/2.1		4.5/0.6	Avg/σ:	55.4/4.9		3.85/0.10	Avg/σ:	53.5/2.7		3.6/0.44	Avg/σ:	24.7/2.8		2.6/0.15
Condition 3	LH_2	NOT TESTED				1-53	52.6	2	3.7	1-49	57.6	2	4.1	1-51	30.6	2	3.1
LH_2→GHe→LH_2						1-54	49.7	2	3.3	1-50	60.0	2	3.8	1-52	23.1	2	2.3
→Air→LH_2						1-77	36.1	1&2	3.5	1-73	50.1	2	3.7	1-75	20.6	2	1.9
						1-78	49.3	2	3.4	1-74	46.7	2	4.5	1-76	30.3	2	2.7
						Avg/σ:	46.9/8.0		3.5/0.19	Avg/σ:	53.6/6.5		4.0/0.39	Avg/σ:	26.2/4.9		2.5/0.58
Condition 4	Room Temp	1-25	16.3	2	0.66	1-9	15.9	2	0.70	1-1	14.2	5	0.66	1-5	11.4	5	0.92
LH_2→GHe→LH_2		1-26	16.2	2	0.72	1-10	14.7	2	0.60	1-2	13.4	2	0.64	1-6	10.7	5	0.79
→Air		1-27	17.6	2	0.68	1-11	13.4	2	0.61	1-3	12.2	2	0.54	1-7	9.2	5	1.00
		1-28	17.9	2	0.89	1-12	15.2	2	0.74	1-4	12.3	5	0.58	1-8	11.3	5	0.86
		Avg/σ:	17.0/0.8		0.74/0.1	Avg/σ:	15.2/1.2		0.65/0.07	Avg/σ:	13.0/1.0		0.62/0.06	Avg/σ:	10.6/1.1		0.9/0.10
Condition 5	Room Temp	NOT TESTED				1-21	15.3	2	0.67	1-13	10.9	5	No Data	NOT TESTED			
LH_2→GHe→LH_2						1-22	14.4	2&3	0.69	1-14	12.1	5	0.77				
→Air→300°F→Air						1-23	14.2	2	No Data	1-15	12.3	2	0.70				
						1-24	13.1	2	No Data	1-16	12.3	2	0.64				
						Avg/σ:	14.2/1.1		0.68/0.02	Avg/σ:	11.9/0.7		0.70/0.06				
Condition 6	Room Temp	1-17	17.6	2	1.01	NOT TESTED				NOT TESTED				NOT TESTED			
As Received		1-18	19.2	2	1.15												
		1-19	16.0	2	1.04												
		1-20	15.5	2	1.13												
		Avg/σ:	17.1/1.8		1.08/0.07												

*Type of Break

1 - Gage length
2 - Point of tangency
3 - Rivets and/or grip
4 - Static
5 - Combination of delamination, tangency, and/or shear

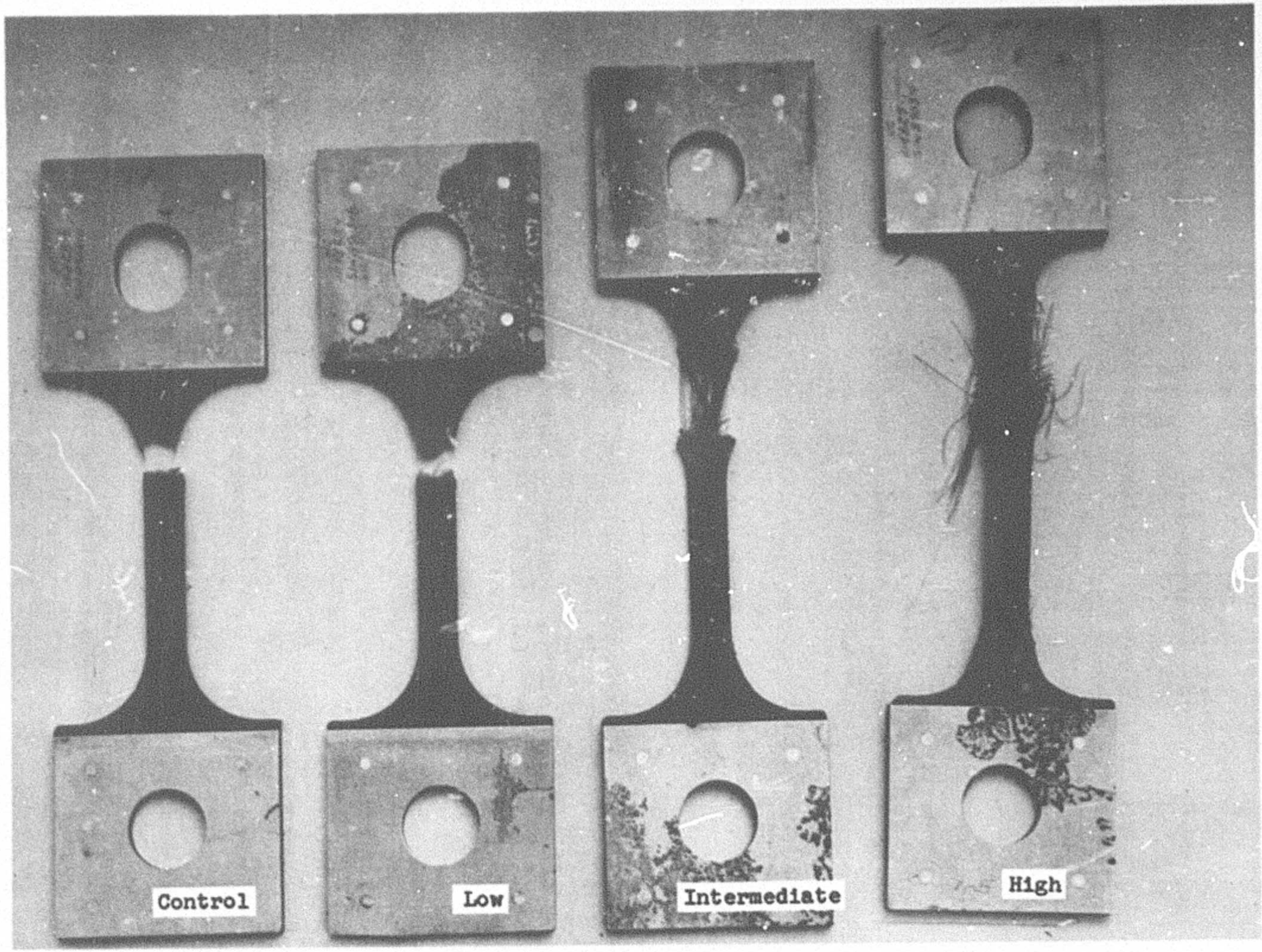

Figure 3-9 Armalon 405-CL-116: Fractured Specimens Pulled at Room Temperature after Exposure to Low, Intermediate, and High Gamma Doses

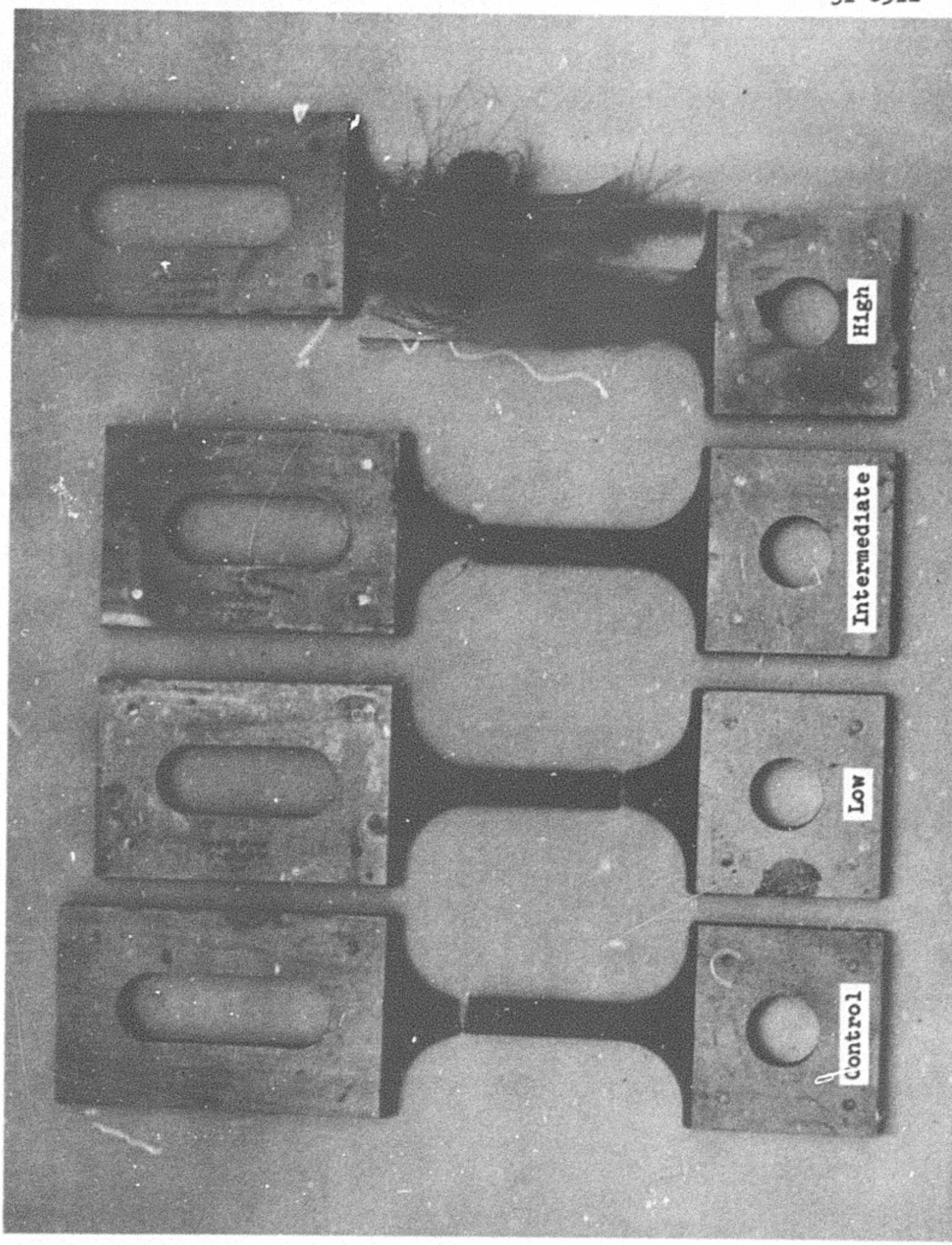

Figure 3-10 Armalon 405-CL-116: Fractured Specimens Pulled at LH_2 Temperature after Exposure to Low, Intermediate, and High Gamma Doses

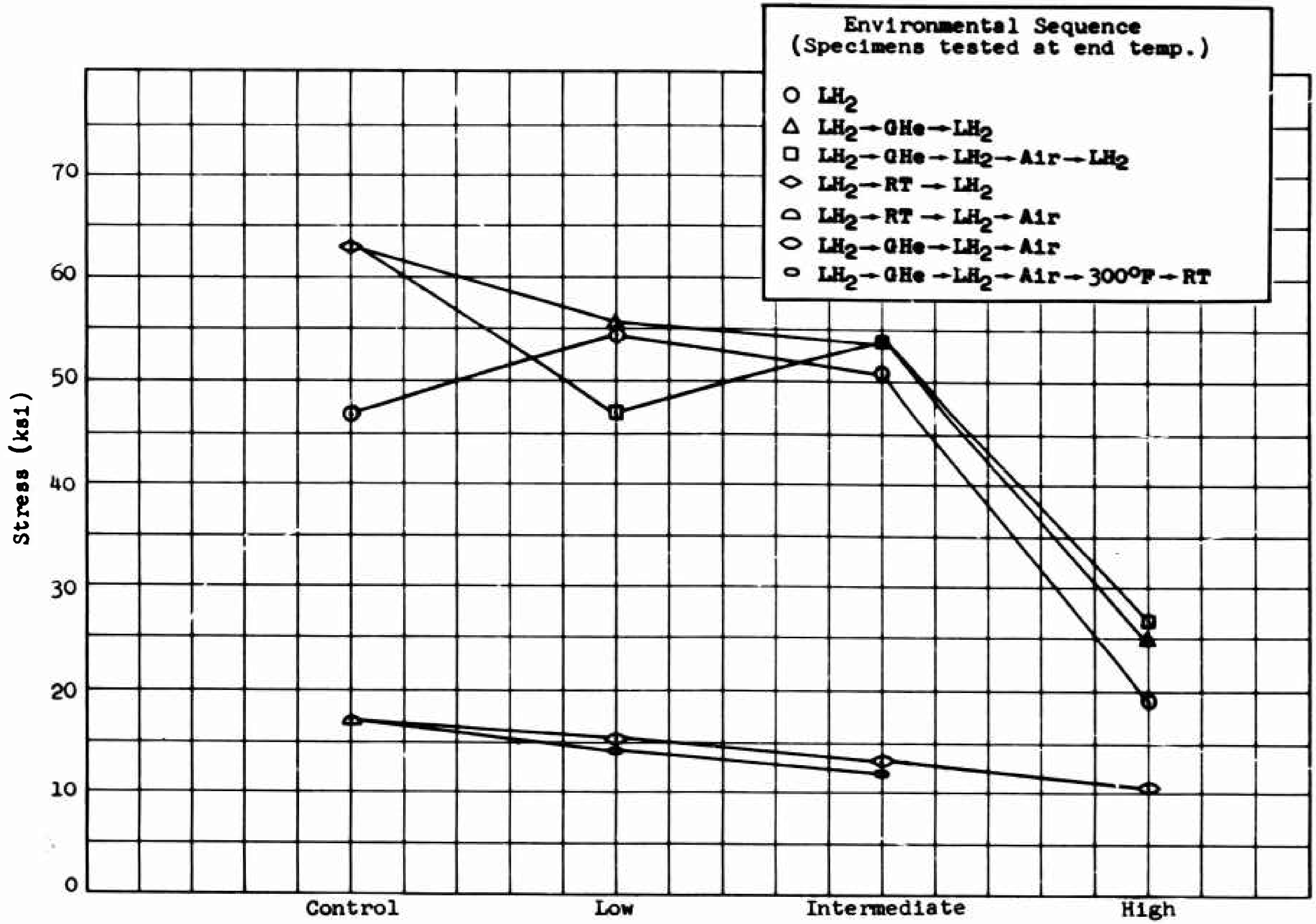

Figure 3-11 **Armalon 405-CL-116: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Tensile Strength**

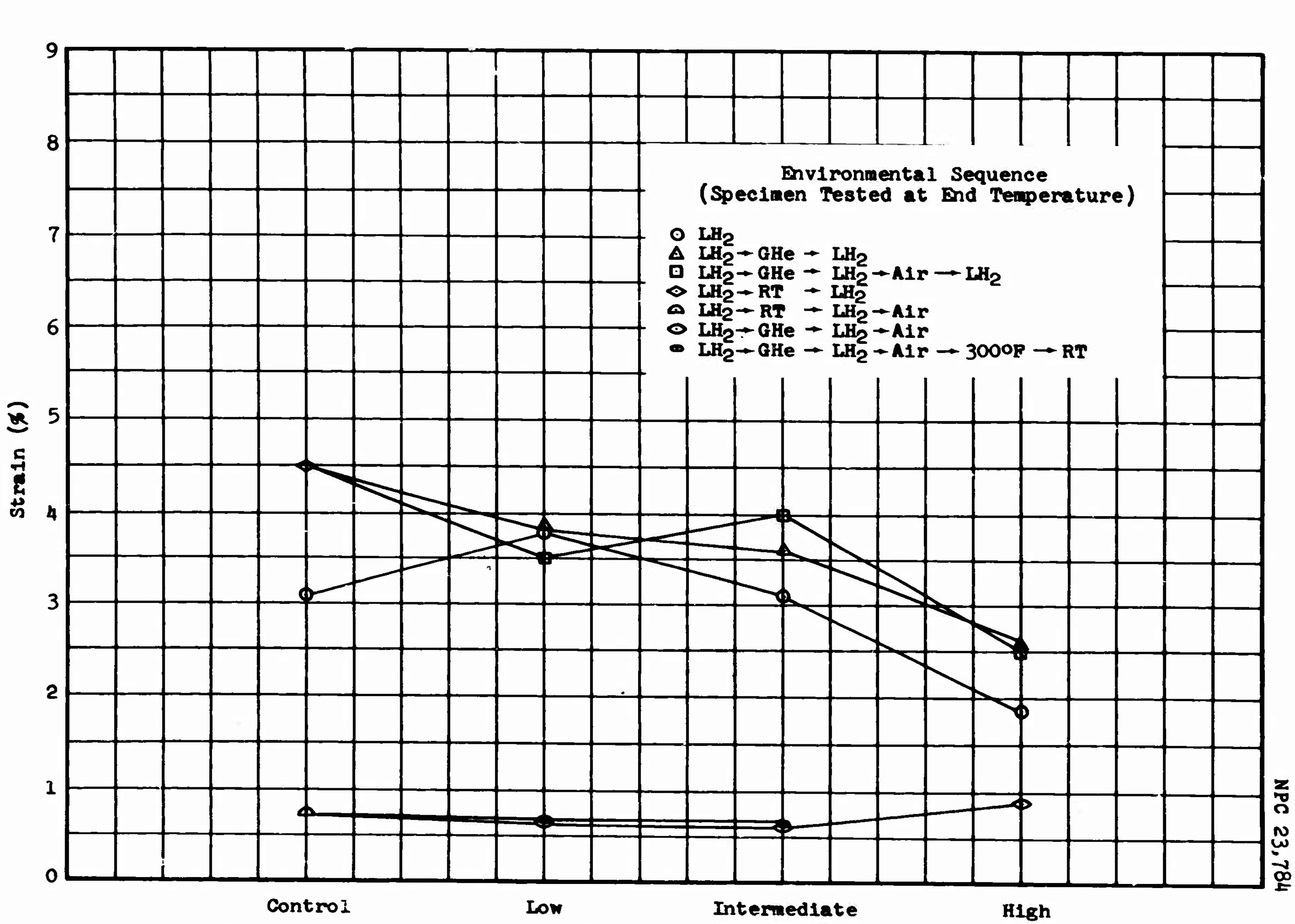

Figure 3-12 Armalon 405-CL-116: Effect of Gamma Dose and Post-irradiation Environmental Sequence on Ultimate Strain

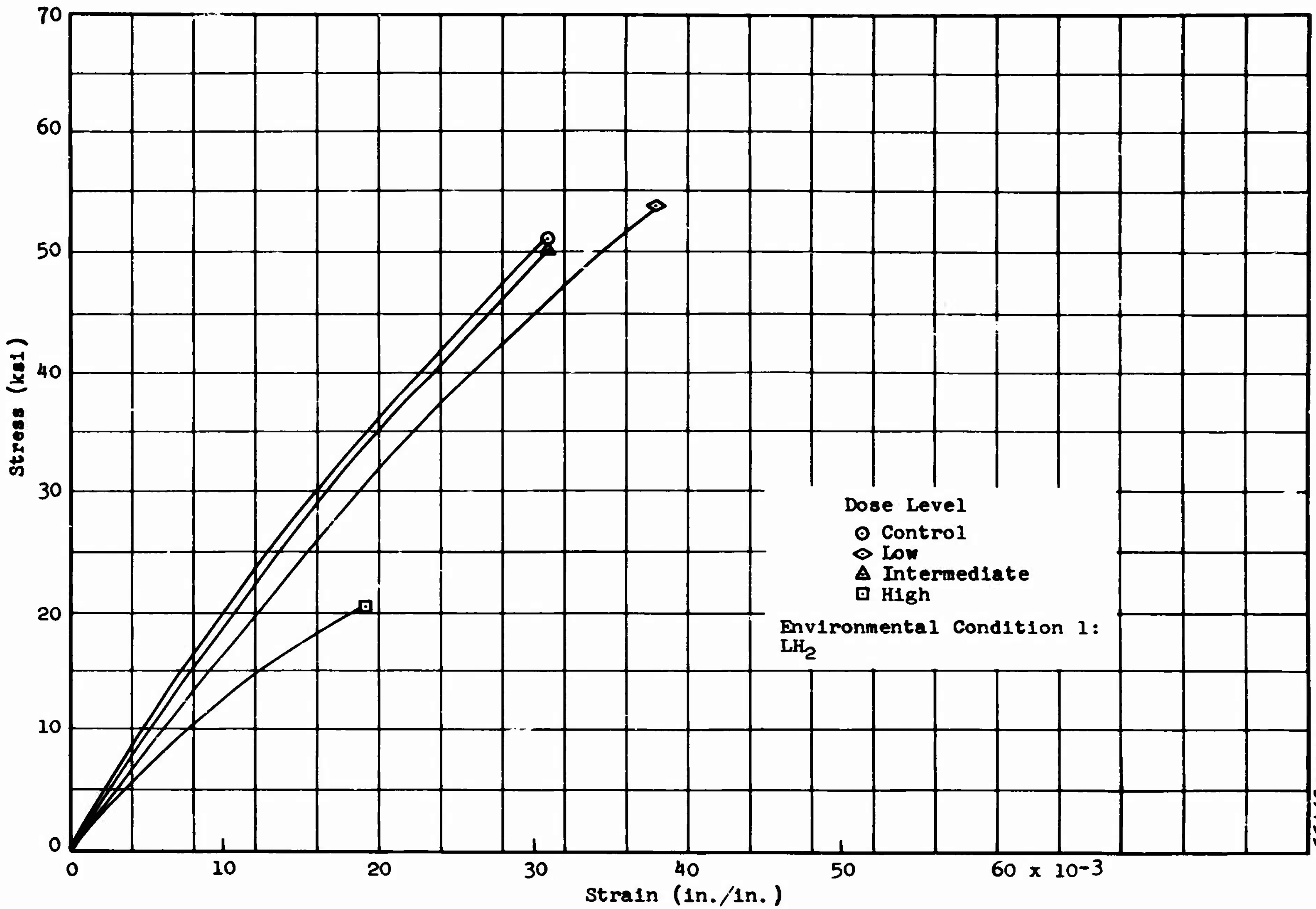

Figure 3-13 Armalon 405-CL-116: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 1

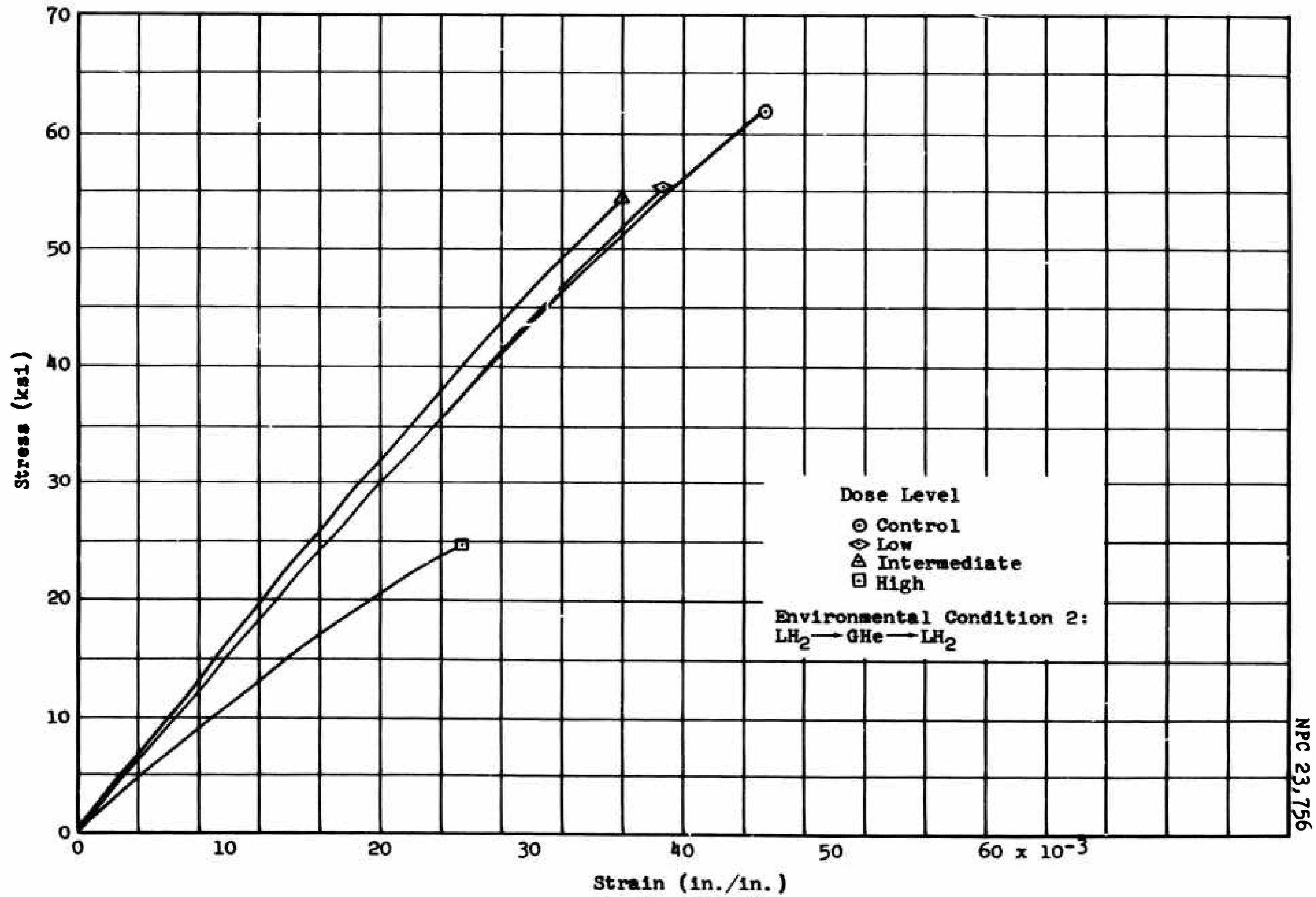

Figure 3-14 Armalon 405-CL-116: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 2

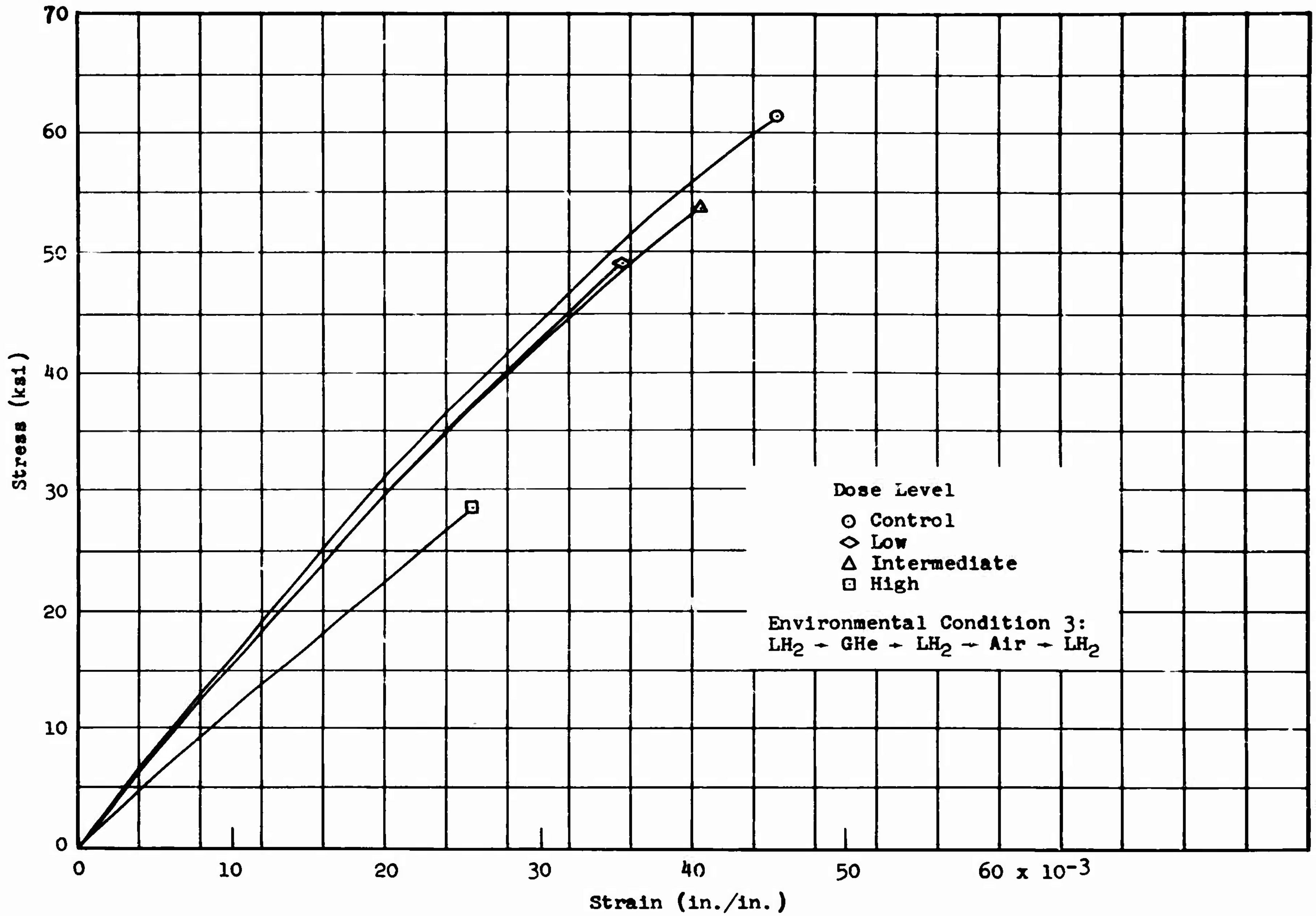

Figure 3-15 **Armalon 405-CL-116: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 3**

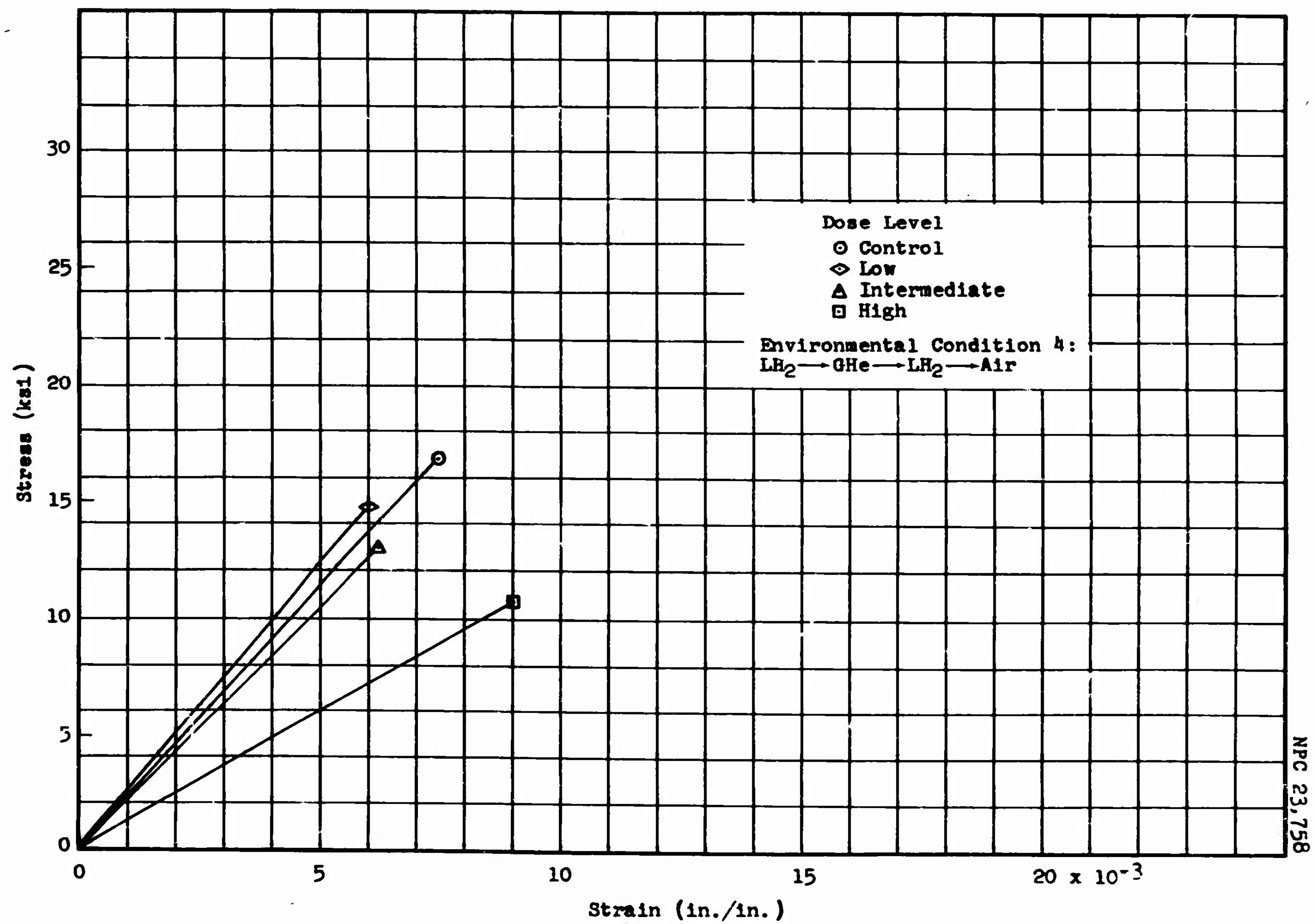

Figure 3-16 Armalon 405-CL-116: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 4

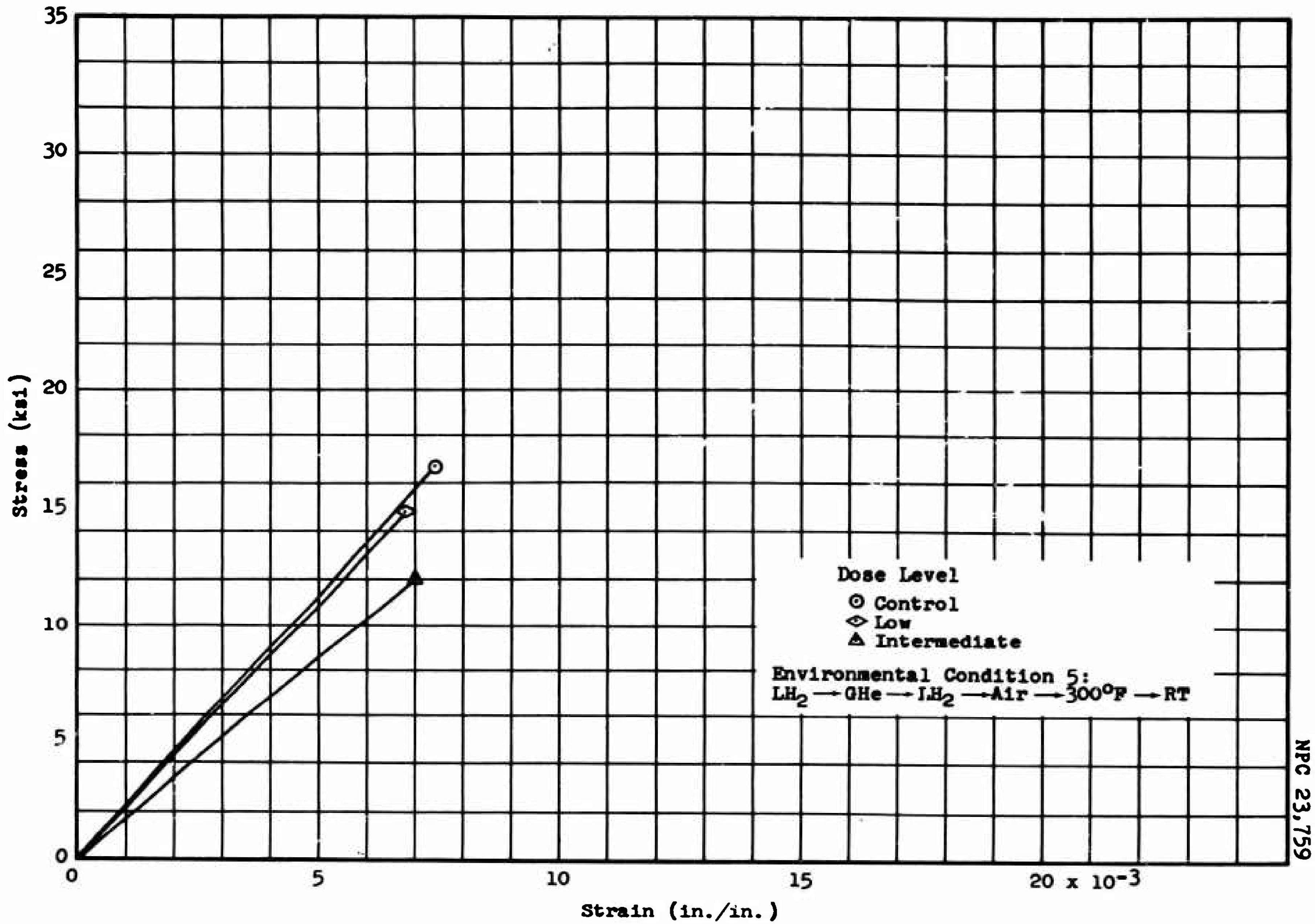

Figure 3-17 Armalon 405-CL-116: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 5

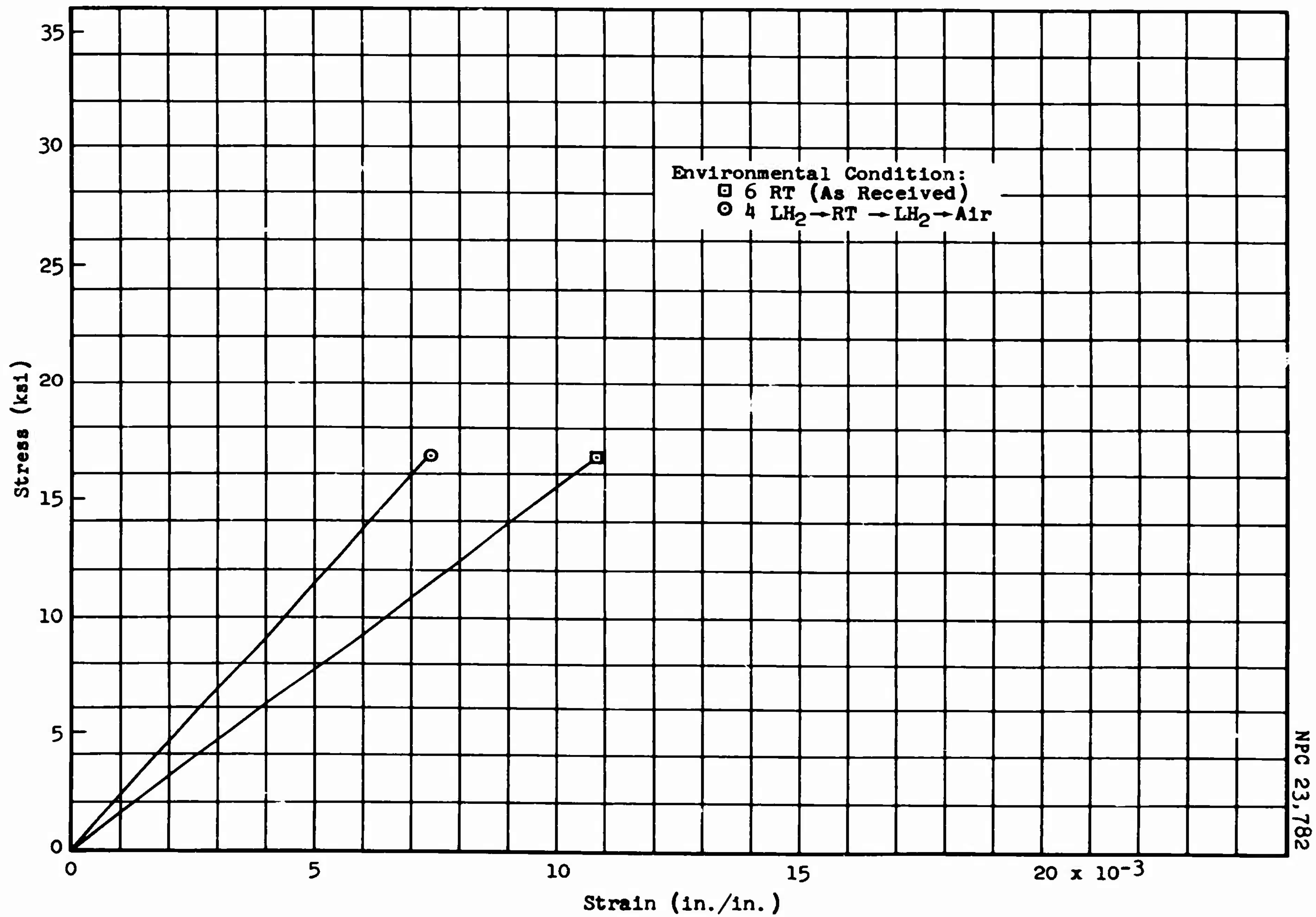

Figure 3-18 Armalon 405-CL-116: Stress-Strain Curves of Control Specimens Showing Effect of Environmental Condition 4 vs 6

X-RAY DIFFRACTION STUDY

SPECIMEN		X-RAY METHOD
Material	Armalon 405-CL-116	Cu Tgt. Ni Fltr.
Form	1/8-in. Sheet	R. M. 16-1-4
Condition	Laminate	Slit 0.006

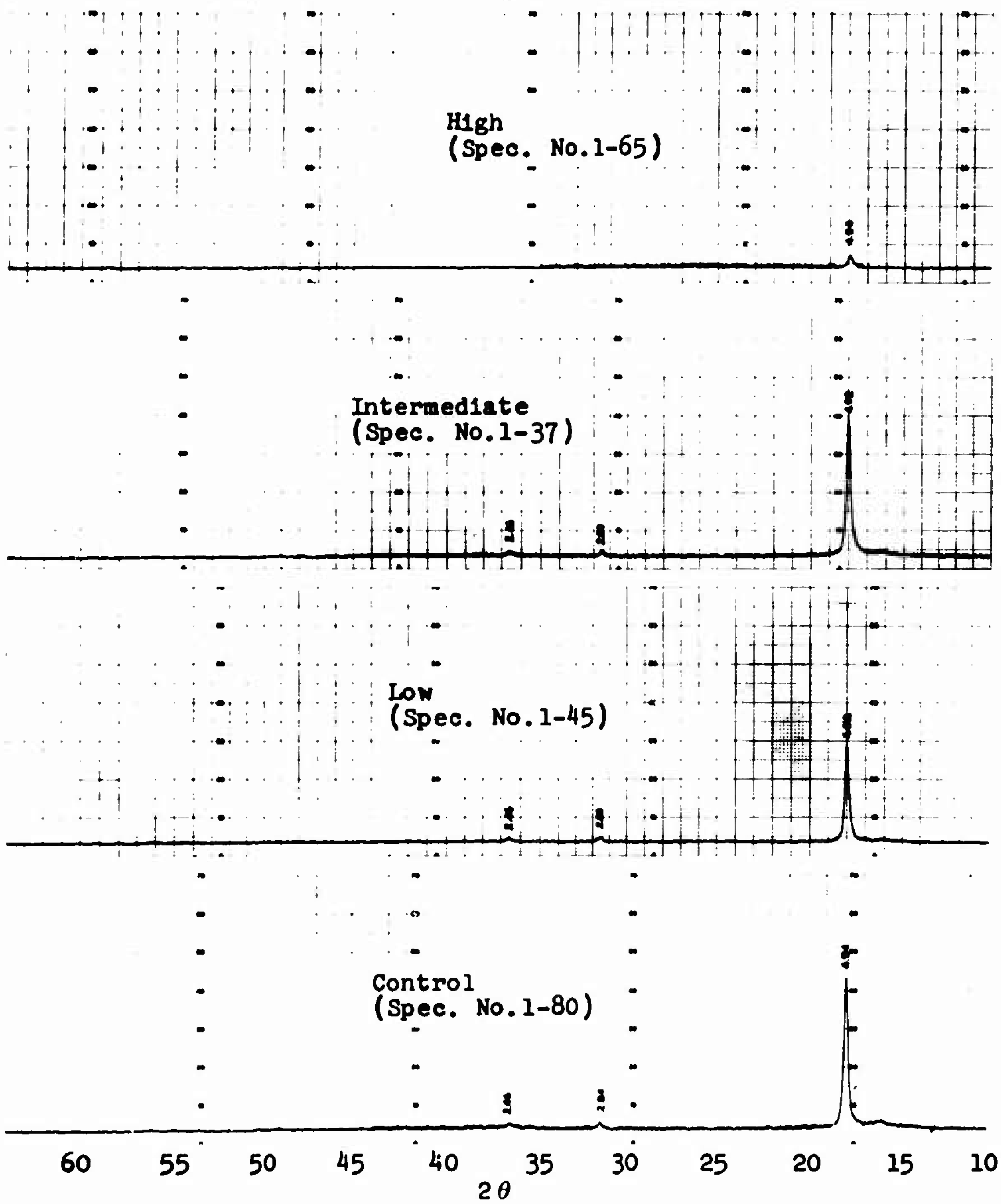

Figure 3-19 Armalon 405-CL-116: Comparison of X-Ray Diffraction Data for a Typical Set of Specimens Exposed to Different Dose Levels and Tested at Environmental Condition 1

3.2.2
Armalon TFE-405-L-112

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3.2.2 Armalon TFE-405-L-112

This material was tested at all test conditions, but with some difficulty at the high-dose condition; the specimens tended to deform outside the gage length to the extent that more than one specimen was pulled at once. This makes the high-dose strain and load data for conditions 1 and 2 almost impossible to interpret. On the second loading, for condition 3, the specimen spacing was increased and the data are considered more reliable.

The typical failure location of these specimens was also outside the gage length and in several cases the fracture was in or through the grip. A comparison of typical failures can be seen in Figures 3-20 and 3-21.

A comparison of the ultimate tensile strength at the different dose and environmental conditions is presented in Figure 3-22. These data indicate some damage at the intermediate-dose condition and considerable damage at the high-dose condition. A comparison of ultimate strain at the different test conditions is presented in Figure 3-23. These data indicate a definite degradation of the material at the high-dose condition.

Considerable data scatter was encountered with this material. A post test follow-up uncovered the fact that the specimens

of this material were fabricated from four large 0.125-in.-thick sheets. The detailed data are presented in Table 3-2, with the sheet numbers identified with the specimens. From these data is is obvious that there is an extremely high variation between sheets. Because of this wide variation, the data are rather difficult to interpret and impractical to average. No stress-strain curves are included, but a detailed consideration of the data is included in the statistical analysis (Sec. 3.3).

The x-ray diffraction studies showed no radiation-induced change at any of the conditions. A typical set of x-ray data is shown as Figure 3-24.

Table 3-2

Armalon 405-L-112: Ultimate Tensile Strength and Elongation

Environmental Sequence	Test Temp	Control				Low Dose				Intermediate Dose				High Dose			
		Specimen No.*	Stress (ksi)	Type of Break**	Strain (%)	Specimen No.*	Stress (ksi)	Type of Break**	Strain (%)	Specimen No.*	Stress (ksi)	Type of Break**	Strain (%)	Specimen No.*	Stress (ksi)	Type of Break**	Strain (%)
Condition 1		2-55(B)	37.3	1	3.5	2-45(A)	72.6	2	5.2	2-37(A)	64.5	2	4.7	2-41(A)	50.3	3&5	No Data
LH_2	LH_2	2-56(B)	37.9	1	3.8	2-69(D)	57.8	2	5.1	2-61(B)	23.5	2	3.1	2-65(B)	40.5	5	No Data
		2-79(C)	52.8	2	4.6	2-47(A)	71.3	3	6.0	2-39(A)	62.4	2	4.1	2-43(A)	44.0	5	No Data
		2-80(C)	32.3	2	2.4	2-71(D)	61.3	2	4.7	2-63(B)	20.9	2	2.9	2-67(D)	39.8	5	No Data
		Avg:	40.0		3.6	Avg:	65.8		5.3	Avg:	42.8		3.7	Avg:	43.6		
Condition 2		2-57(B)	36.6	1	3.9	2-46(A)	71.5	2	5.7	2-38(A)	69.6	2	5.6	2-42(A)	51.6	5	No Data
LH_2-GHe-LH_2	LH_2	2-58(B)	34.7	2	3.6	2-48(C)	26.3	2	1.8	2-40(A)	69.1	2	6.5	2-66(B)	39.6	5	No Data
		2-81(C)	53.7	2	4.4	2-70(B)	33.7	2	2.9	2-62(B)	No Data	2	No Data	2-44(A)	65.4	2	No Data
		2-82(C)	53.0	2	4.3	2-72(D)	61.0	2	4.8	2-64(B)	27.0	2	3.3	2-68(D)	28.3	5	No Data
		Avg:	44.5		4.1	Avg:	48.1		3.8	Avg:	41.4		5.1	Avg:	46.2		
Condition 3		NOT TESTED				2-53(B)	37.2	2	3.9	2-49(B)	27.5	2	4.2	2-51(B)	18.9	2	No Data
LH_2-GHe-LH_2	LH_2					2-54(B)	36.2	2	5.8	2-50(B)	26.4	2	4.1	2-52(B)	20.0	2	No Data
-Air-LH_2						2-77(D)	62.2	2	5.4	2-73(D)	58.8	2	4.0	2-75(C)	17.7	2	1.6
						2-78(D)	58.5	2	4.8	2-74(C)	23.9	2	1.9	2-76(C)	24.6	2	2.4
						Avg:	48.5		5.0	Avg:	34.2		3.6	Avg:	20.3		2.0
Condition 4		2-13(A)	21.6	2	No Data	2-9(C)	12.1	2	0.8	2-1(A)	14.7	5	0.6	2-5(A)	13.1	5	0.6
LH_2-GHe-LH_2	Room Temp	2-14(A)	20.5	2	0.9	2-10(A)	17.5	3	0.5	2-2(A)	15.8	5	0.7	2-6(A)	12.5	5	0.6
-Air		2-15(A)	21.1	2	0.9	2-11(A)	18.6	3	0.7	2-3(A)	15.5	5	0.7	2-7(A)	12.7	5	0.8
		2-16(A)	20.9	2	1.0	2-12(A)	18.3	3	0.4	2-4(A)	16.6	5	0.6	2-8(A)	13.2	5	0.7
		Avg:	21.0		0.9	Avg:	16.6		0.6	Avg:	15.6		0.65	Avg:	12.9		0.68
Condition 5		NOT TESTED				NOT TESTED				NOT TESTED				2-17(A)	12.9	5	0.8
LH_2-GHe-LH_2	Room Temp													2-18(A)	13.6	5	0.6
-Air-300°F-Air														2-19(A)	13.2	5	0.8
														2-20(A)	12.5	5	No Data
														Avg:	13.1		0.7
Condition 6		2-21(C)	14.4	2	1.2	NOT TESTED				NOT TESTED				NOT TESTED			
As Received	Room Temp	2-22(C)	14.2	2	1.3												
		2-23(C)	13.4	2	1.2												
		2-24(C)	14.3	2	1.2												
		Avg:	14.1		1.2												

*The letter in parentheses indicates batch variation.

**Type of Break

1 - Gage length
2 - Point of tangency
3 - Rivets and/or grip
4 - Static
5 - Combination of delamination, tangency, and/or shear

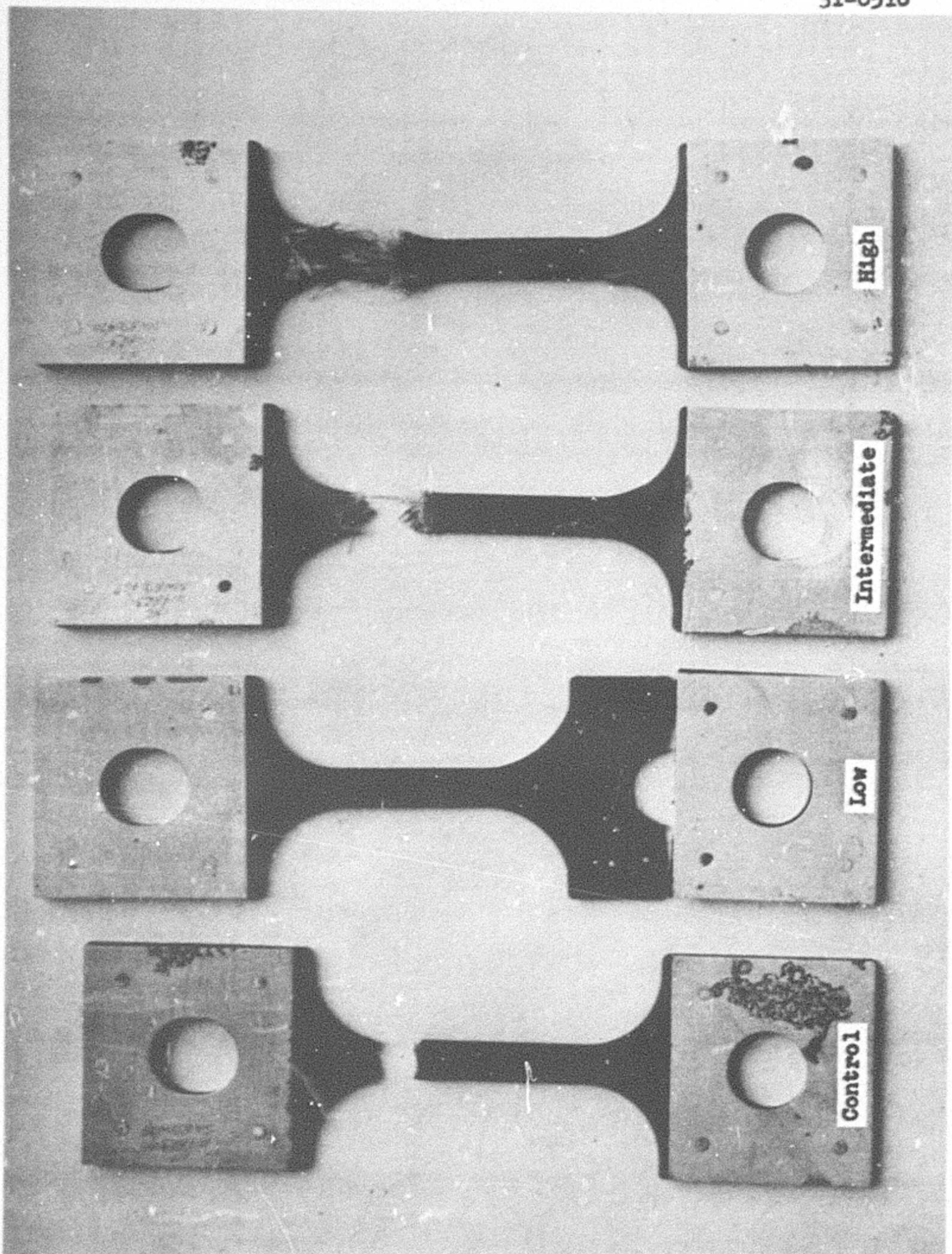

Figure 3-20 Armalon 405-L-112: Fractured Specimens Pulled at Room Temperature after Exposure to Low, Intermediate, and High Gamma Doses

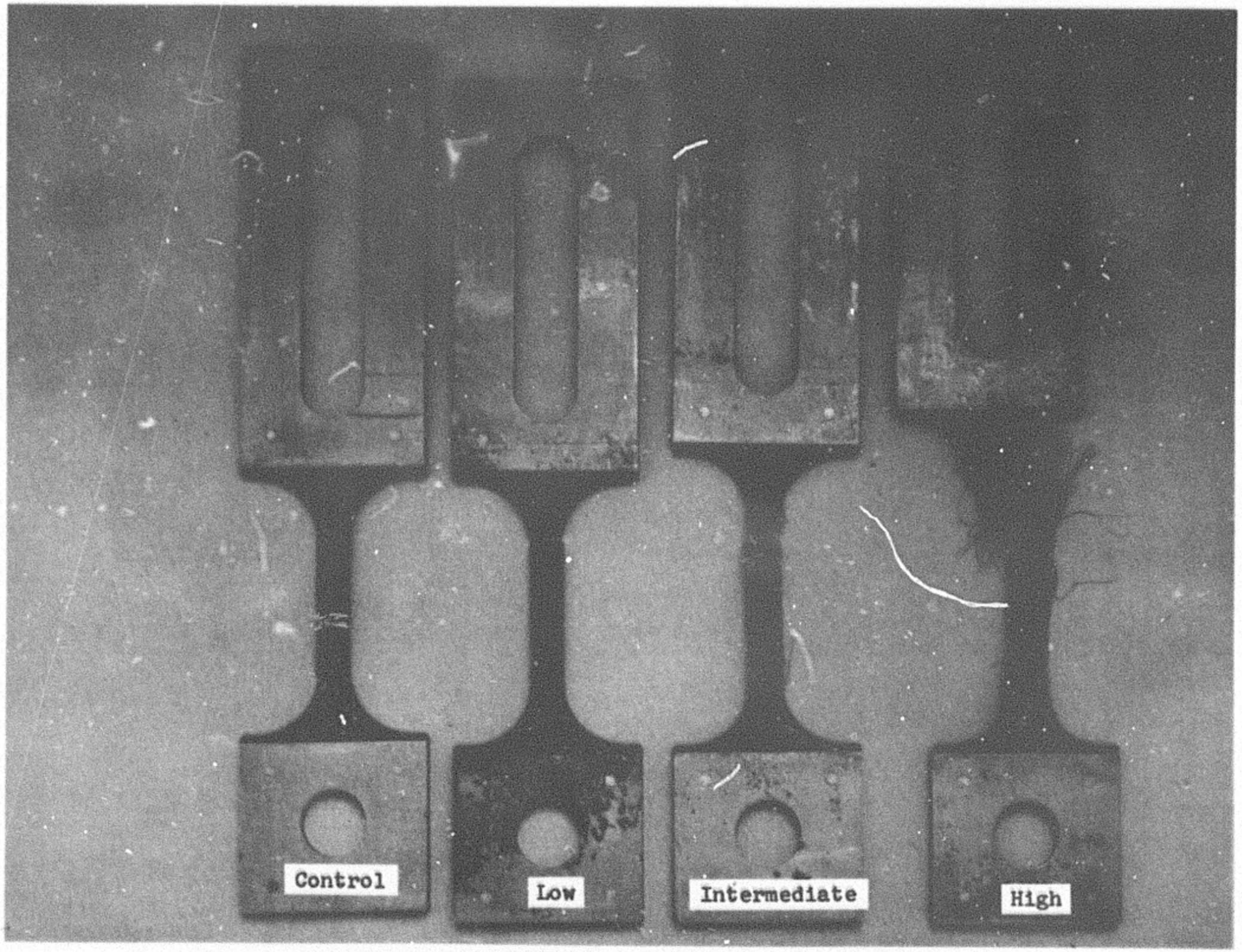

Figure 3-21 Armalon 405-L-112: Fractured Specimens Pulled at LH_2 Temperature after Exposure to Low, Intermediate, and High Gamma Doses

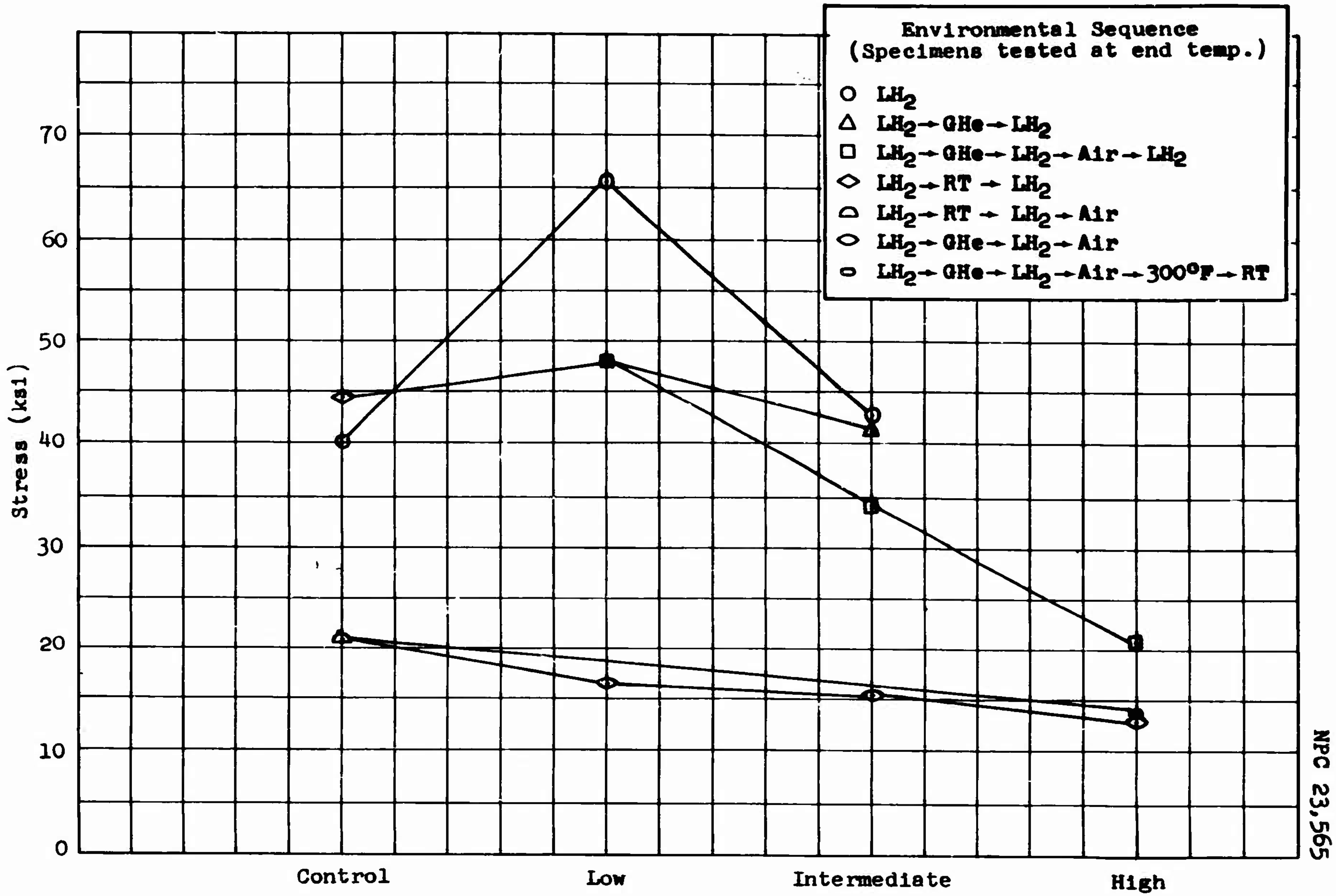

Figure 3-22 Armalon 405-L-112: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Tensile Strength

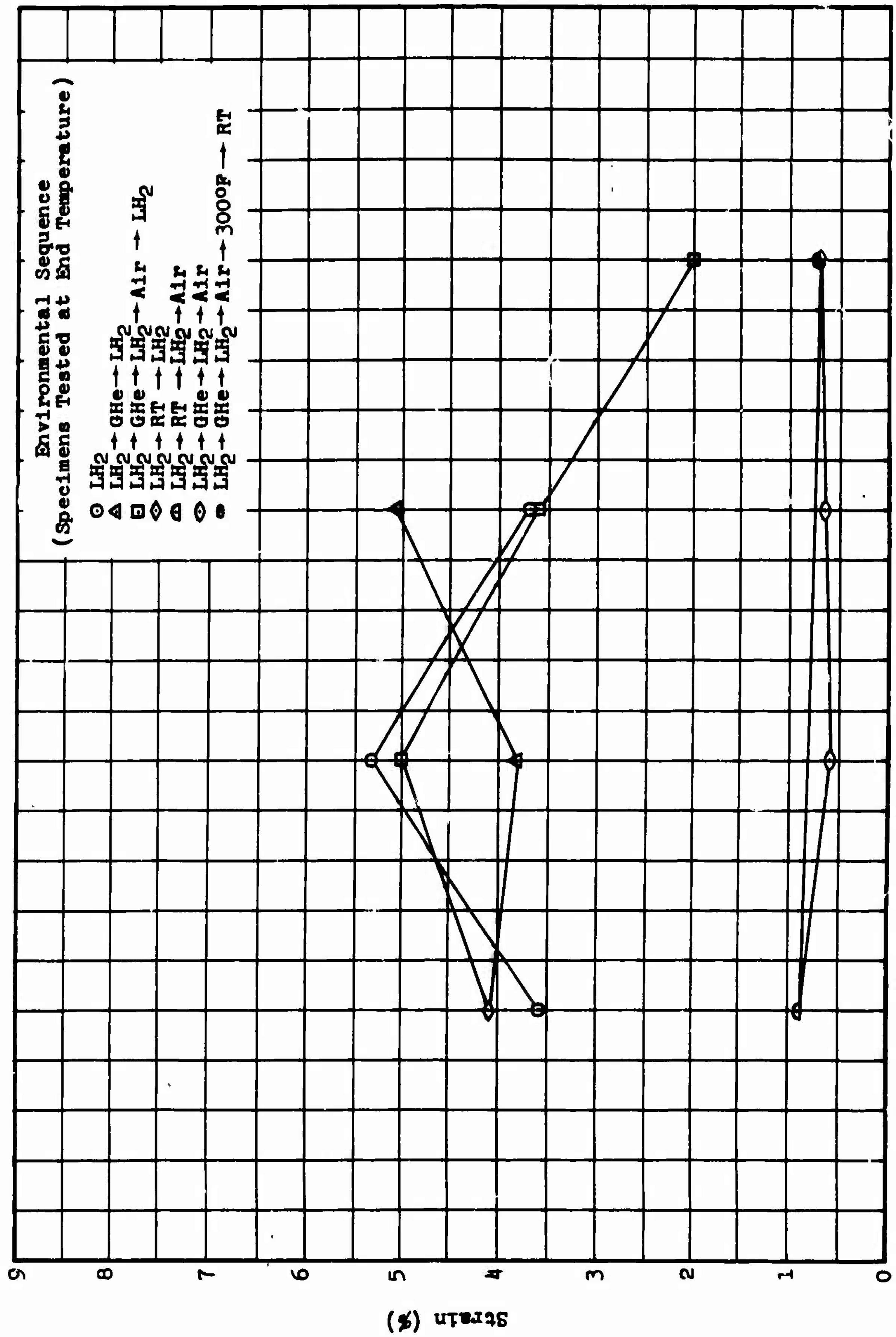

Figure 3-23 Armalon 405-L-112: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Strain

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X-RAY DIFFRACTION STUDY

SPECIMEN		X-RAY METHOD
Material	Armalon 405-L-112	Cu Tgt. Ni Fltr.
Form	1/8-in Sheet	R. M. 16-1-4
Condition	Laminate	Slit 0.006

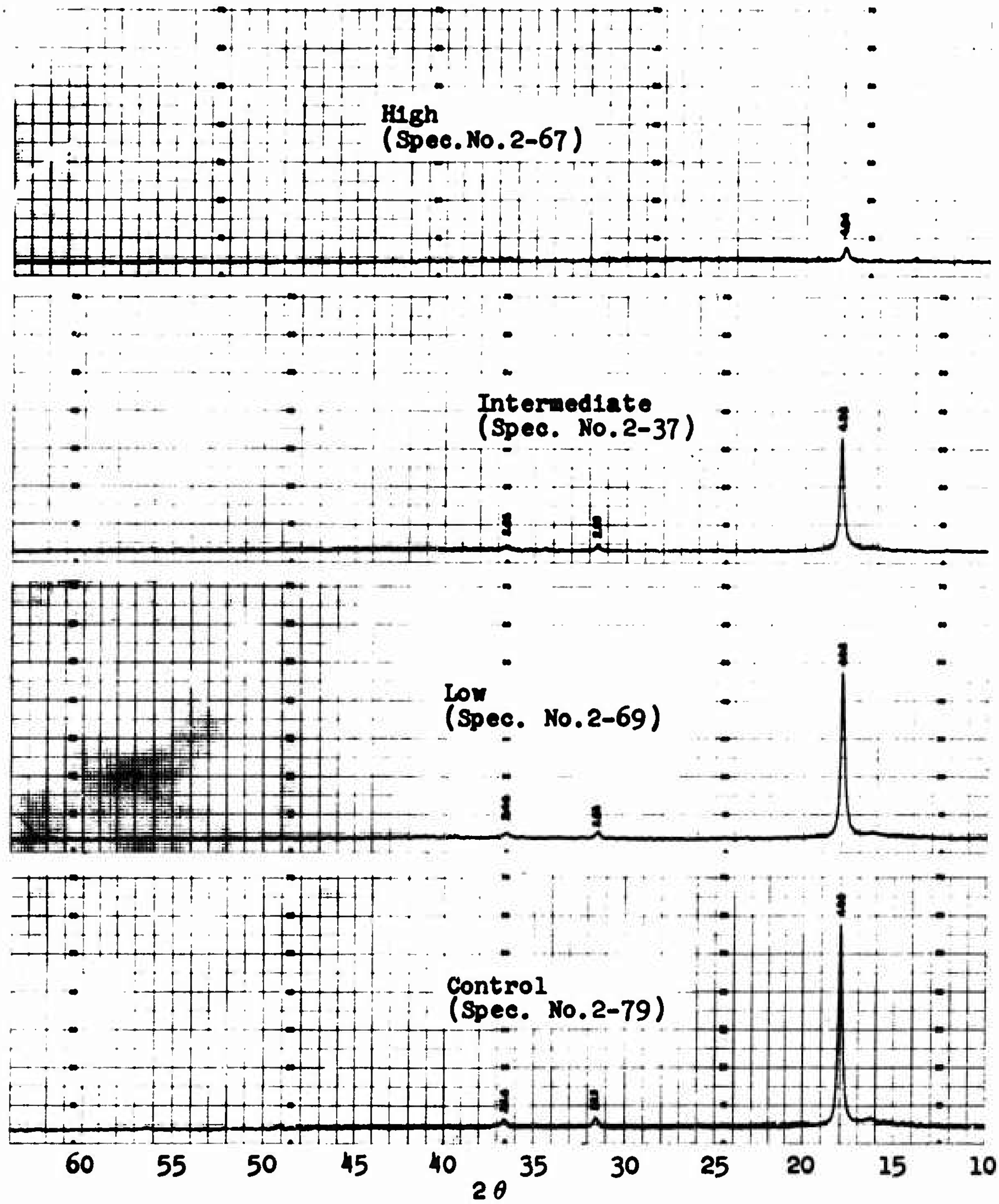

Figure 3-24 Armalon 405-L-112: Comparison of X-Ray Diffraction Data for a Typical Set of Specimens Exposed to Different Dose Levels and Tested at Environmental Condition 1

3.2.3
Armalon FEP-510-L-128

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3.2.3 Armalon FEP-510-L-128

This material was tested satisfactorily at all conditions, and the data were found to be very consistent. The fractures for this type of Armalon were also at the point of tangency for the specimens tested at both LH_2 and room temperatures. Representative fractures of this material can be seen in Figures 3-25 and 3-26.

A comparison of the ultimate tensile strength at the different dose and environmental conditions is presented in Figure 3-27. From these data it can be seen that extreme damage was encountered in the specimens that were subjected to the high dose and tested in LH_2; some damage was detected at the intermediate-dose condition, but no radiation effect was noted at the low-dose condition. The specimens tested at room temperature exhibited a gradual decrease in strength with an increase in dose.

A comparison of ultimate strain at the different test conditions is presented in Figure 3-28. These data are not as clear-cut as the stress data, but some decrease is indicated at the high-dose level.

A tabulation of all mechanical-property data is presented in Table 3-3. A statistical analysis of this data is included in Section 3.3.

Average stress-strain relationships are presented in Figures 3-29 through 3-33, showing the effects of dose level on specimens tested at environmental conditions 1 through 5, respectively. Stress-strain curves showing a comparison of control specimens tested at conditions 4 and 6 are shown in Figure 3-34.

The x-ray diffraction studies showed no radiation-induced change at any of the conditions. A typical set of x-ray data is shown in Figure 3-35.

Table 3-3

Armalon 510-L-128: Ultimate Tensile Strength and Elongation

Environmental Sequence	Test Temp	Control				Low Dose				Intermediate Dose				High Dose			
		Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)
Condition 1		3-55	87.9	1	4.7	3-45	84.4	2	4.8	3-37	69.3	2	4.7	3-41	33.8	5	No Data
LH_2	LH_2	3-56	85.6	2	4.8	3-69	84.5	2	5.2	3-61	69.7	2	5.3	3-65	40.4	5	No Data
		3-79	86.9	2	6.0	3-47	88.7	2	4.7	3-39	66.6	2	4.8	3-43	21.0	5	No Data
		3-80	85.8	2	6.2	3-71	80.4	2	4.0	3-63	68.0	2	4.6	3-67	34.5	5	No Data
		Avg/σ:	86.5/0.6		5.4/0.68	Avg/σ:	84.5/4.0		4.7/0.58	Avg/σ:	68.4/1.5		4.8/0.34	Avg/σ:	32.4/9.4		
Condition 2		3-57	85.9	2	5.0	3-46	87.7	2	4.6	3-38	79.1	2	4.9	3-42	21.6	5	No Data
LH_2→GHe→LH_2	LH_2	3-58	84.0	2	4.8	3-48	87.4	2	4.6	3-40	73.8	2	4.6	3-66	39.6	5	No Data
		3-81	89.5	2	5.4	3-70	89.7	2	5.2	3-62	74.2	2	4.4	3-44	24.4	5	2.4
		3-82	88.0	2	5.9	3-72	88.4	2	4.6	3-64	73.9	2	4.3	3-68	52.2	5	No Data
		Avg/σ:	86.9/2.7		5.3/0.53	Avg/σ:	88.3/1.1		4.8/0.29	Avg/σ:	75.3/2.6		4.6/0.29	Avg/σ:	34.5/14.9		2.4
Condition 3		NOT TESTED				3-53	85.7	2	4.5	3-49	77.4	2	5.2	3-51	18.1	2	1.8
LH_2→GHe→LH_2 →Air→LH_2	LH_2					3-54	85.2	2	4.4	3-50	74.4	2	4.4	3-52	15.1	2	1.9
						3-77	88.6	2	5.9	3-73	79.1	2	5.3	3-75	11.7	2	2.1
						3-78	88.3	2	6.1	3-74	80.4	2	5.8	3-76	21.3	2	1.9
						Avg/σ:	86.9/1.5		5.2/0.82	Avg/σ:	77.8/2.9		5.2/0.68	Avg/σ:	16.6/4.7		1.9/0.14
Condition 4		3-28	26.5	2	1.4	3-9	23.7	2	1.4	3-1	19.0	5	1.6	3-5	9.3	5	1.5
LH_2→GHe→LH_2 →Air	Room Temp	3-29	26.2	2	1.5	3-10	24.1	2	1.1	3-2	18.1	2	No Data	3-6	9.9	5	1.5
		3-30	26.8	3	1.3	3-11	22.3	2	1.2	3-3	18.2	5	1.3	3-7	10.1	5	1.0
		3-31	27.7	3	1.5	3-12	24.1	2	1.5	3-4	18.6	5	1.3	3-8	11.8	5	1.2
		Avg/σ:	26.8/0.7		1.4/0.1	Avg/σ:	23.5/0.9		1.3/0.14	Avg/σ:	18.5/0.4		1.4/0.18	Avg/σ:	10.5/1.2		1.3/0.24
Condition 5		NOT TESTED				3-21	25.0	2	No Data	3-13	13.3	2	1.0	3-17	9.2	5	1.6
LH_2→GHe→LH_2 →Air→300°F→Air	Room Temp					3-22	24.9	2	1.3	3-14	15.3	2	0.9	3-18	8.5	5	1.6
						3-23	24.8	2	No Data	3-15	15.2	2	0.8	3-19	9.0	5	1.6
						3-24	24.5	2	1.0	3-16	14.9	2	1.2	3-20	9.0	5	0.6
						Avg/σ:	24.8/0.13		1.2/0.27	Avg/σ:	14.7/1.0		1.0/0.19	Avg/σ:	8.9/0.4		1.4/0.49
Condition 6		3-32	26.0	2	1.5	NOT TESTED				NOT TESTED				NOT TESTED			
As Received	Room Temp	3-33	26.9	2	1.6												
		3-34	26.8	2	1.7												
		3-35	27.3	2	1.6												
		Avg/σ:	26.8/0.6		1.6/0.1												

*Type of Break

1 - Gage length
2 - Point of tangency
3 - Rivets and/or grip
4 - Static
5 - Combination of delamination, tangency, and/or shear

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31-8515

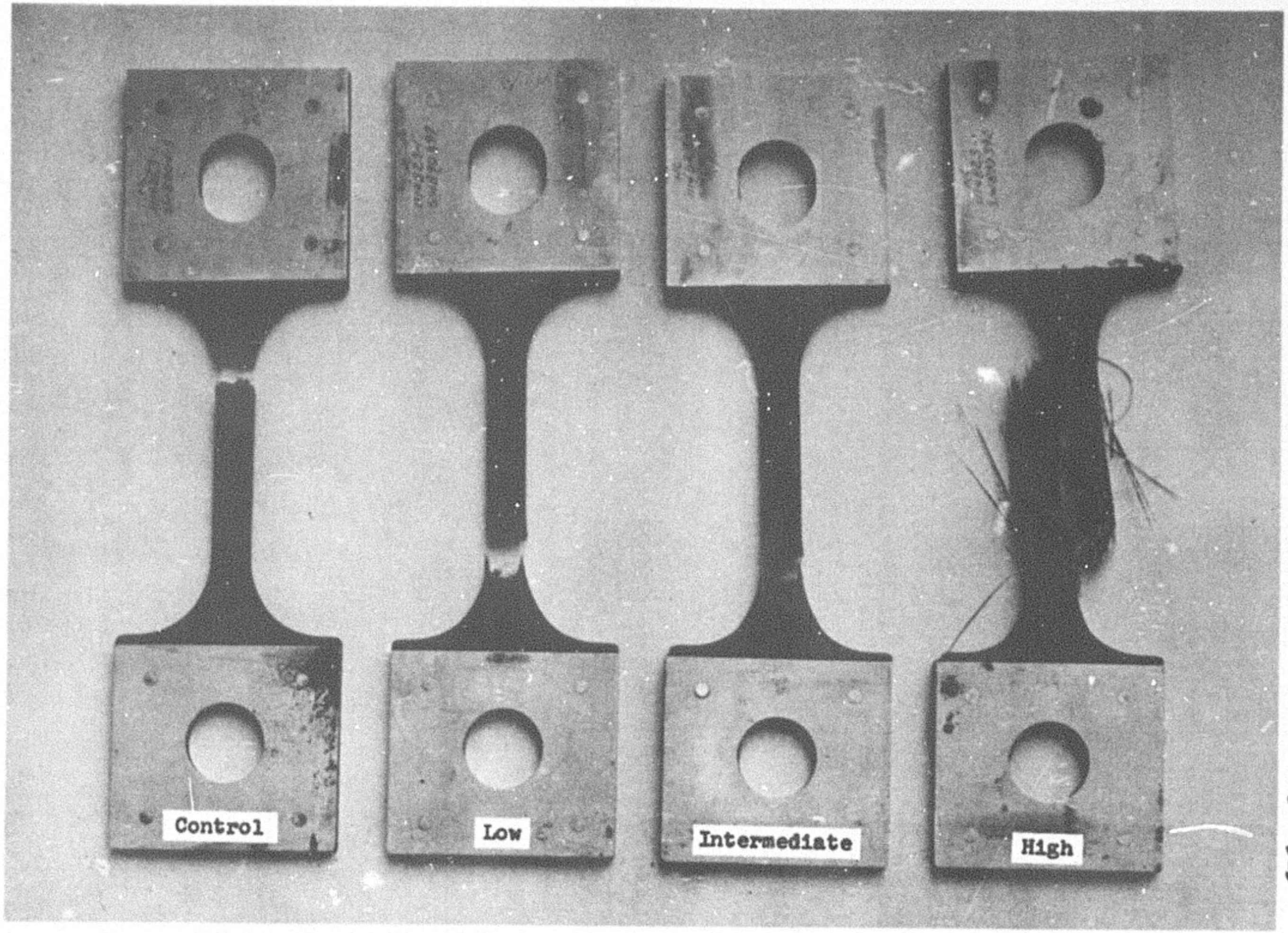

Figure 3-25 Armalon 510-L-128: Fractured Specimens Pulled at Room Temperature after Exposure to Low, Intermediate, and High Gamma Doses

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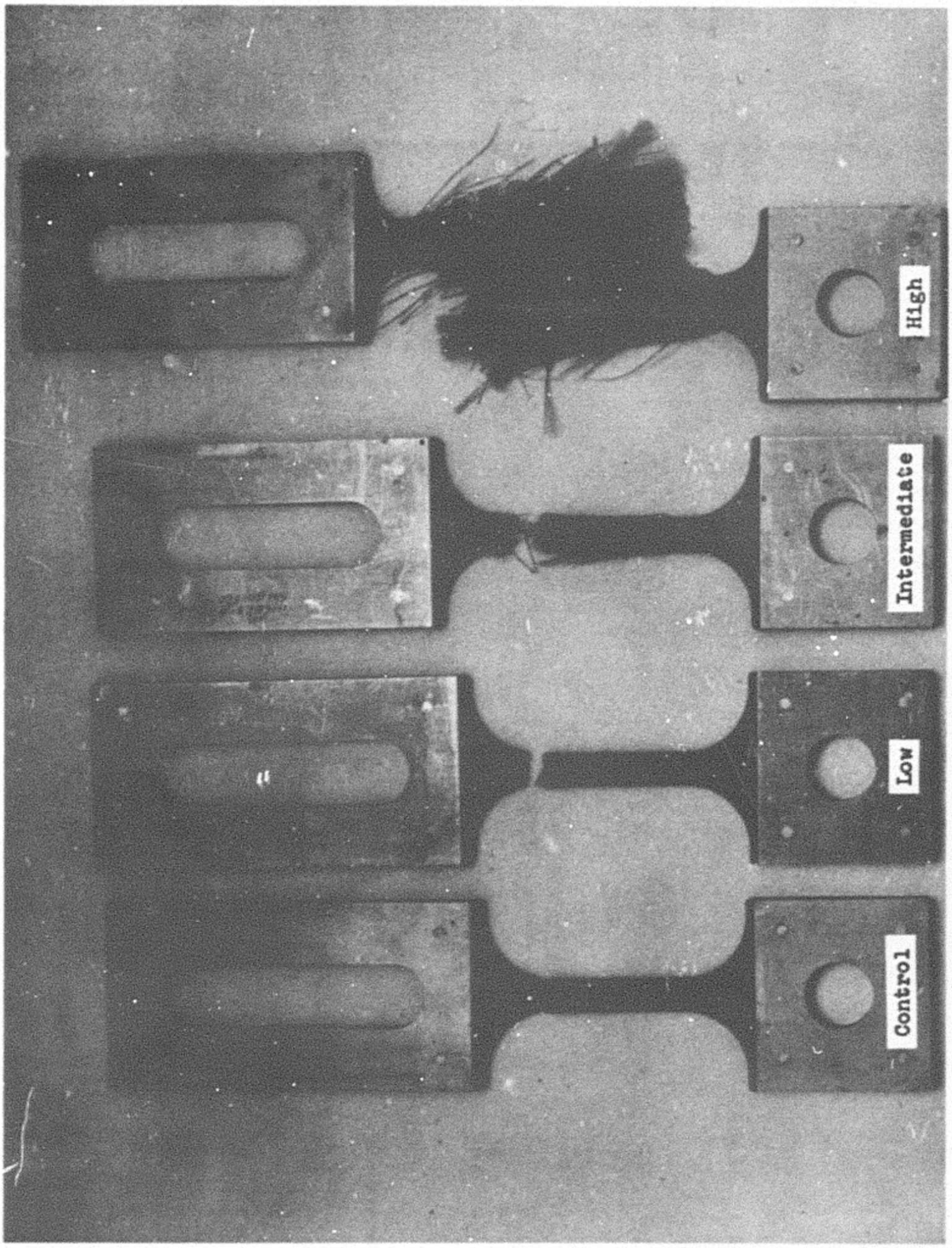

Figure 3-26 Armalon 510-L-128: Fractured Specimens Pulled at LH_2 Temperature after Exposure to Low, Intermediate, and High Gamma Doses

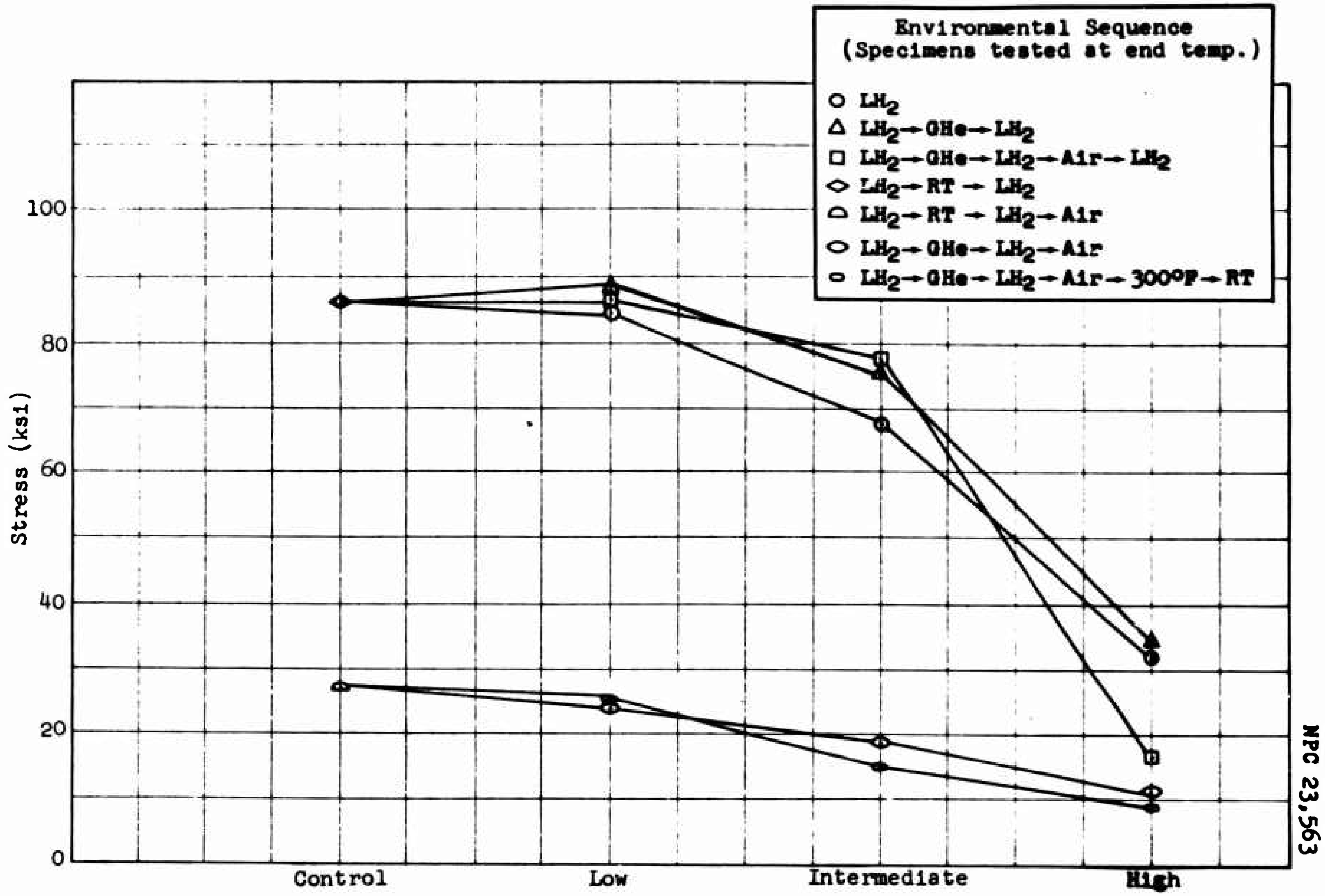

Figure 3-27 Armalon 510-L-128: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Tensile Strength

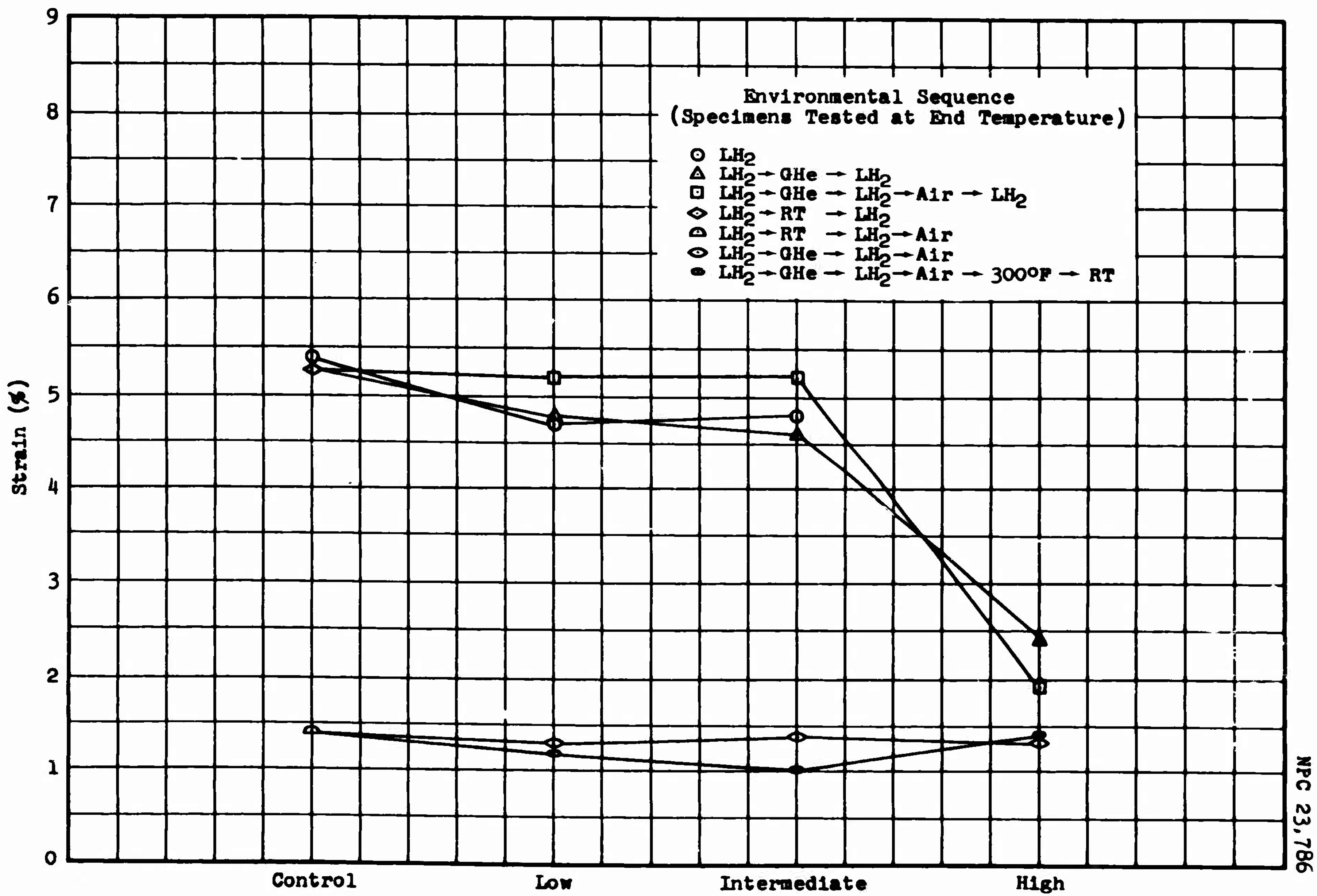

Figure 3-28 Armalon 510-L-128: Effect of Gamma Dose and Post-irradiation Environmental Sequence on Ultimate Strain

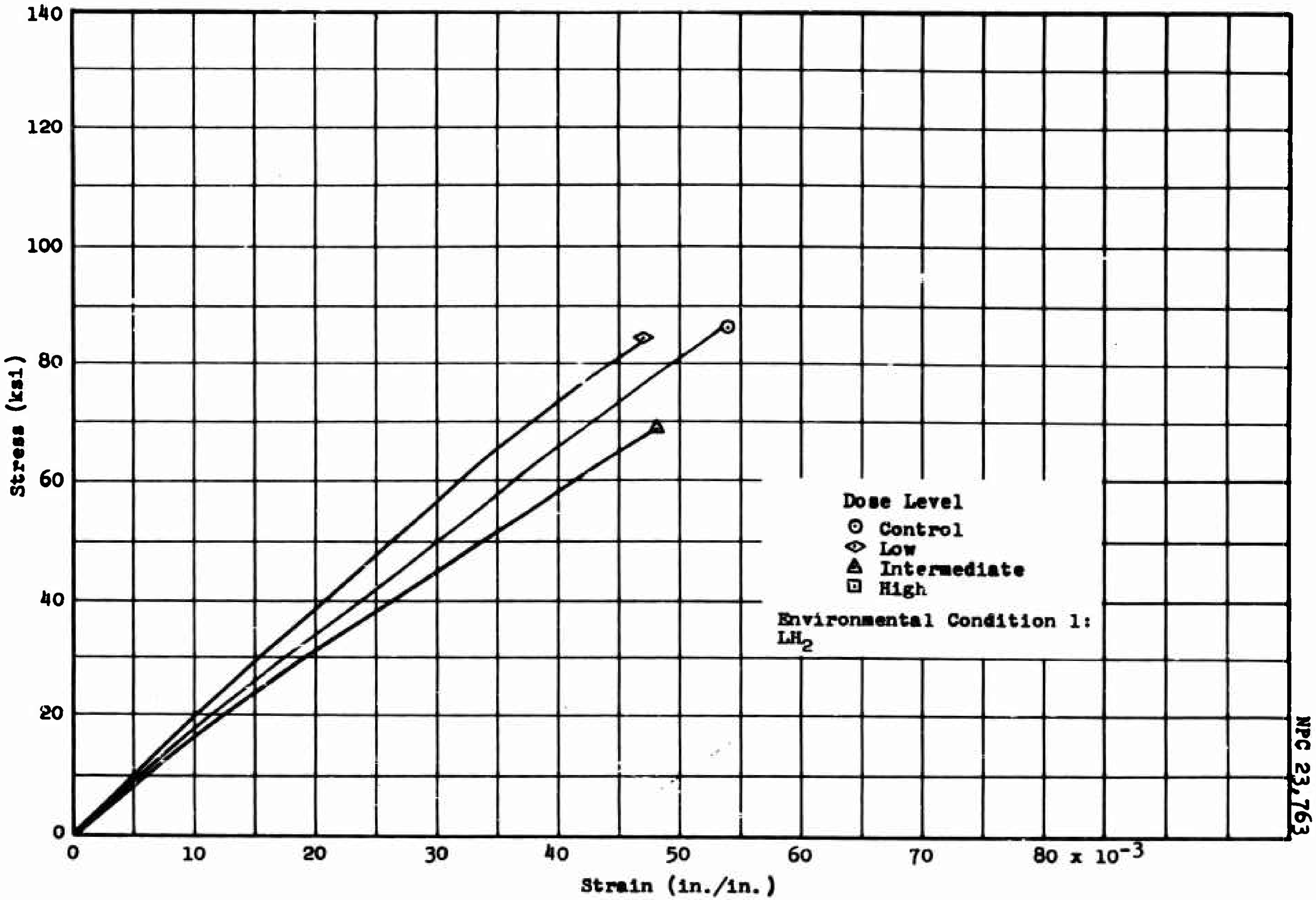

Figure 3-29 Armalon 510-L-123: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 1

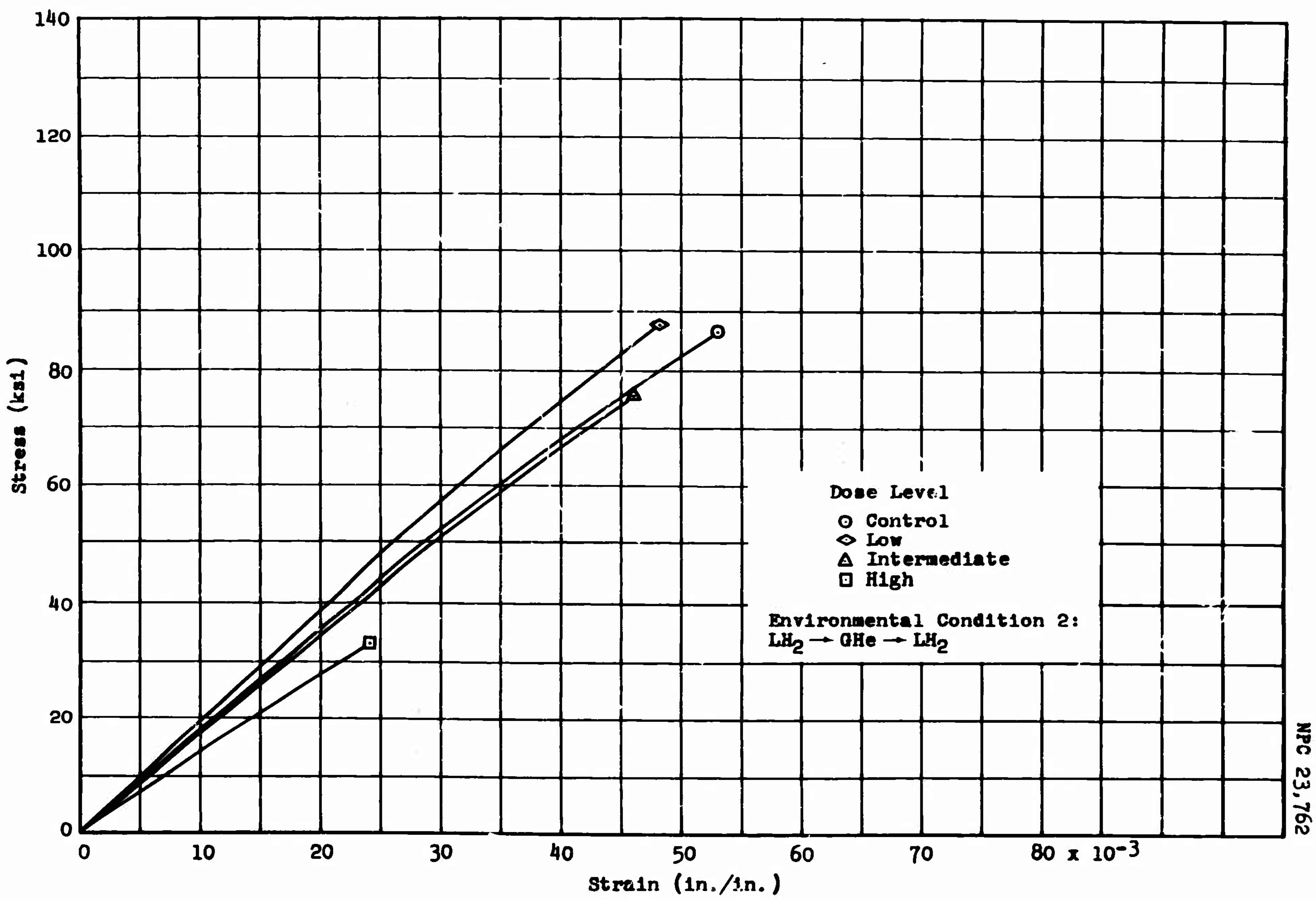

Figure 3-30 Armalon 510-L-128: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 2

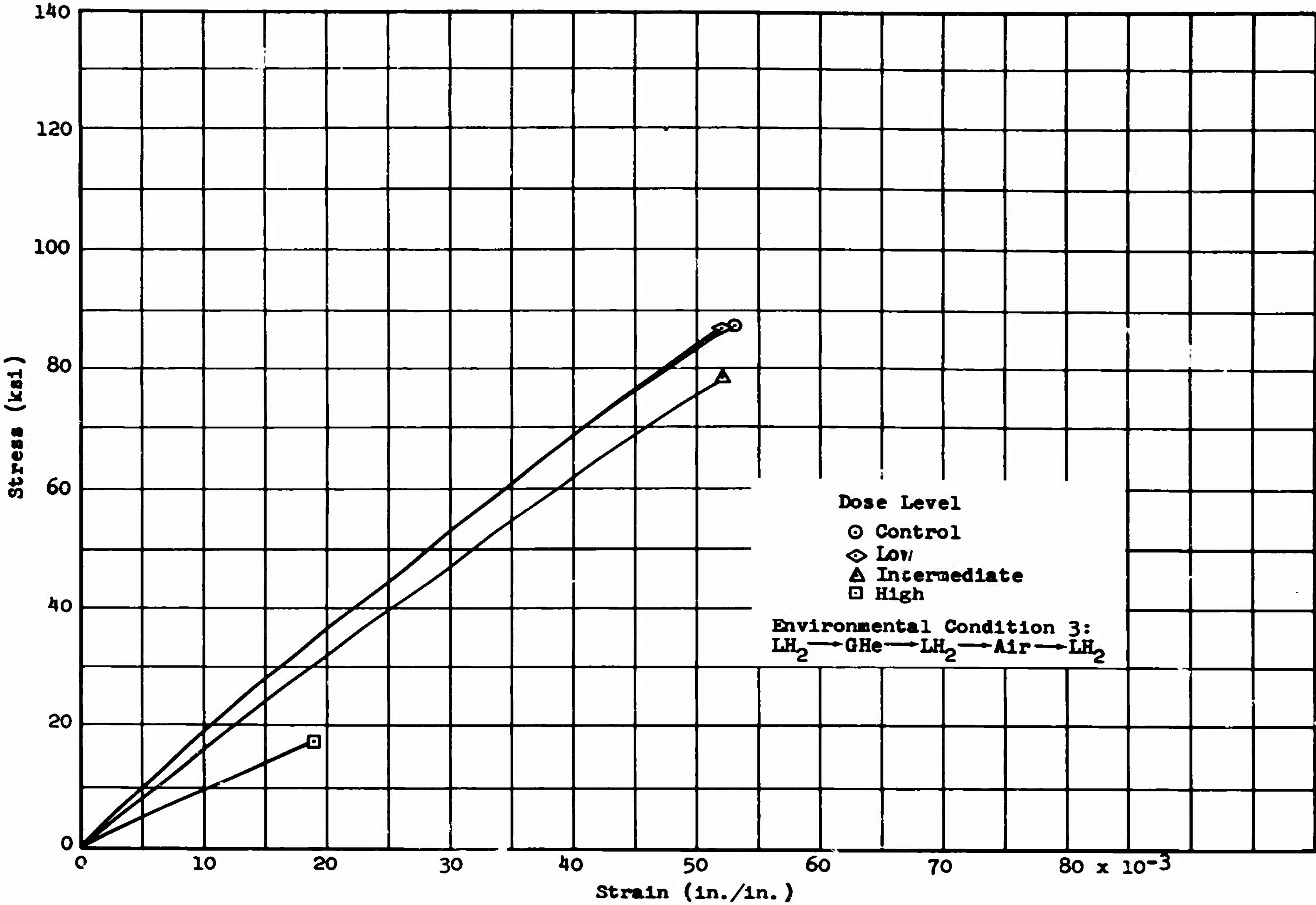

Figure 3-31 Armalon 510-L-128: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 3

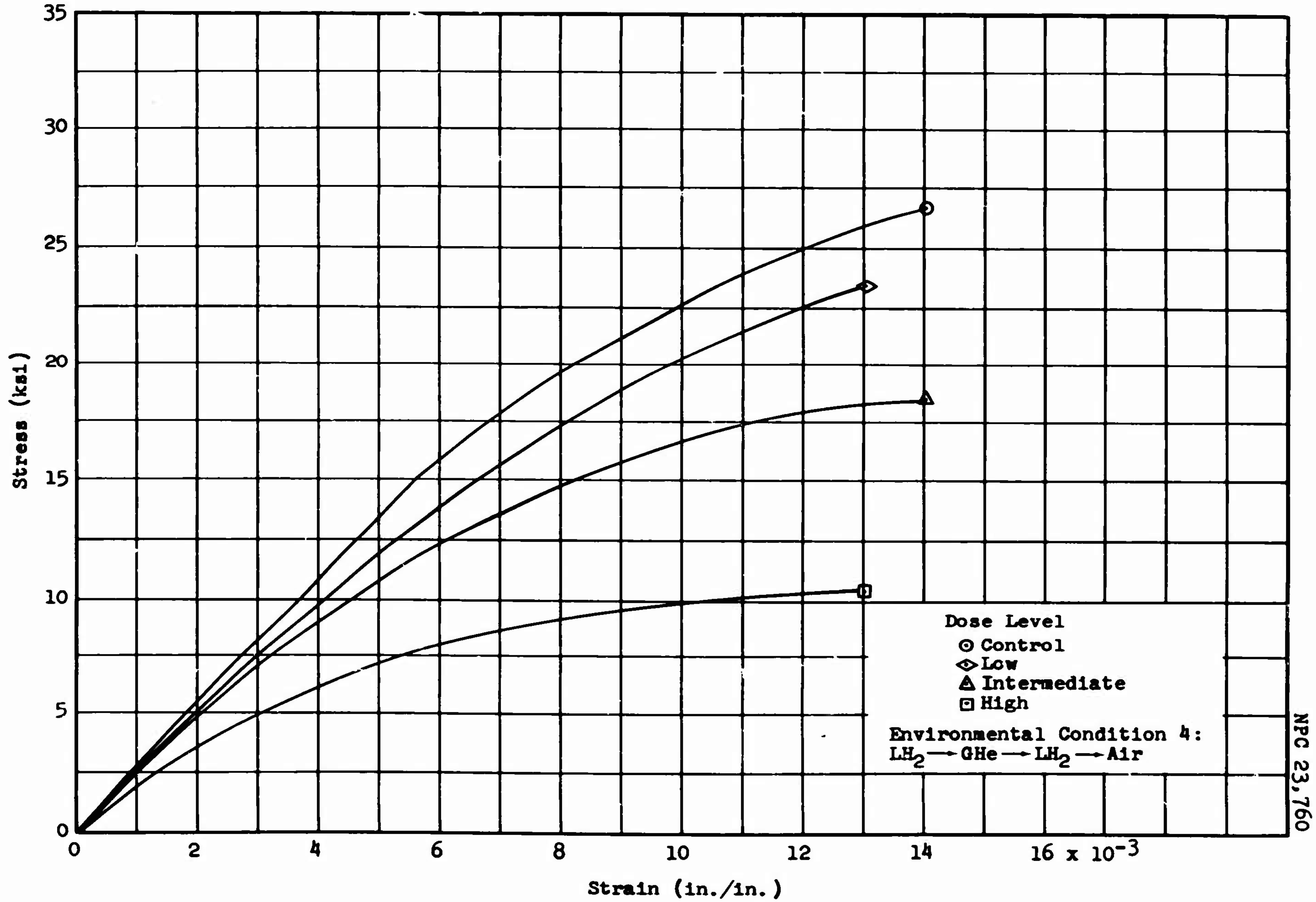

Figure 3-32 Armalon 510-L-128: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 4

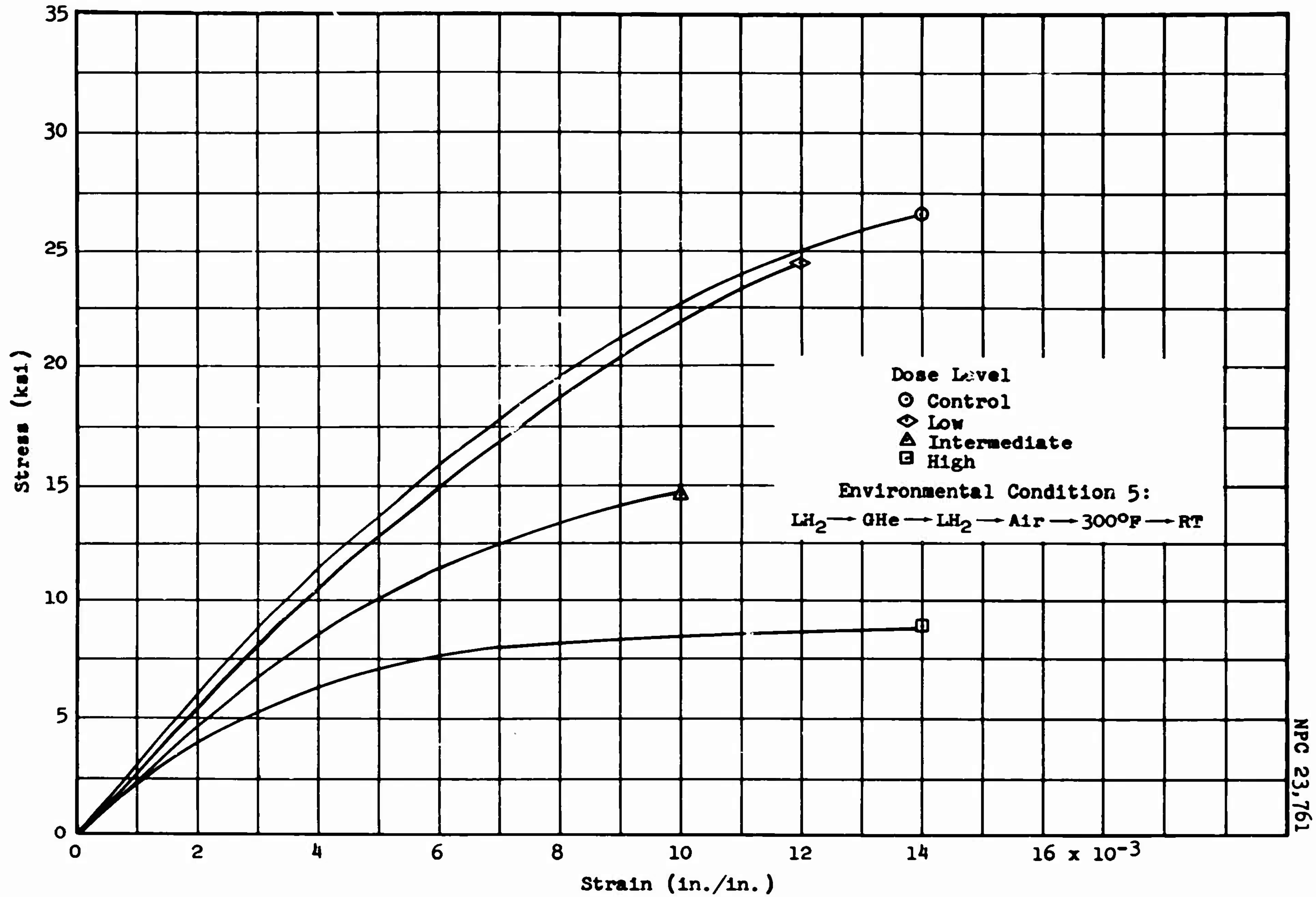

Figure 3-33 Armalon 510-L-128: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 5

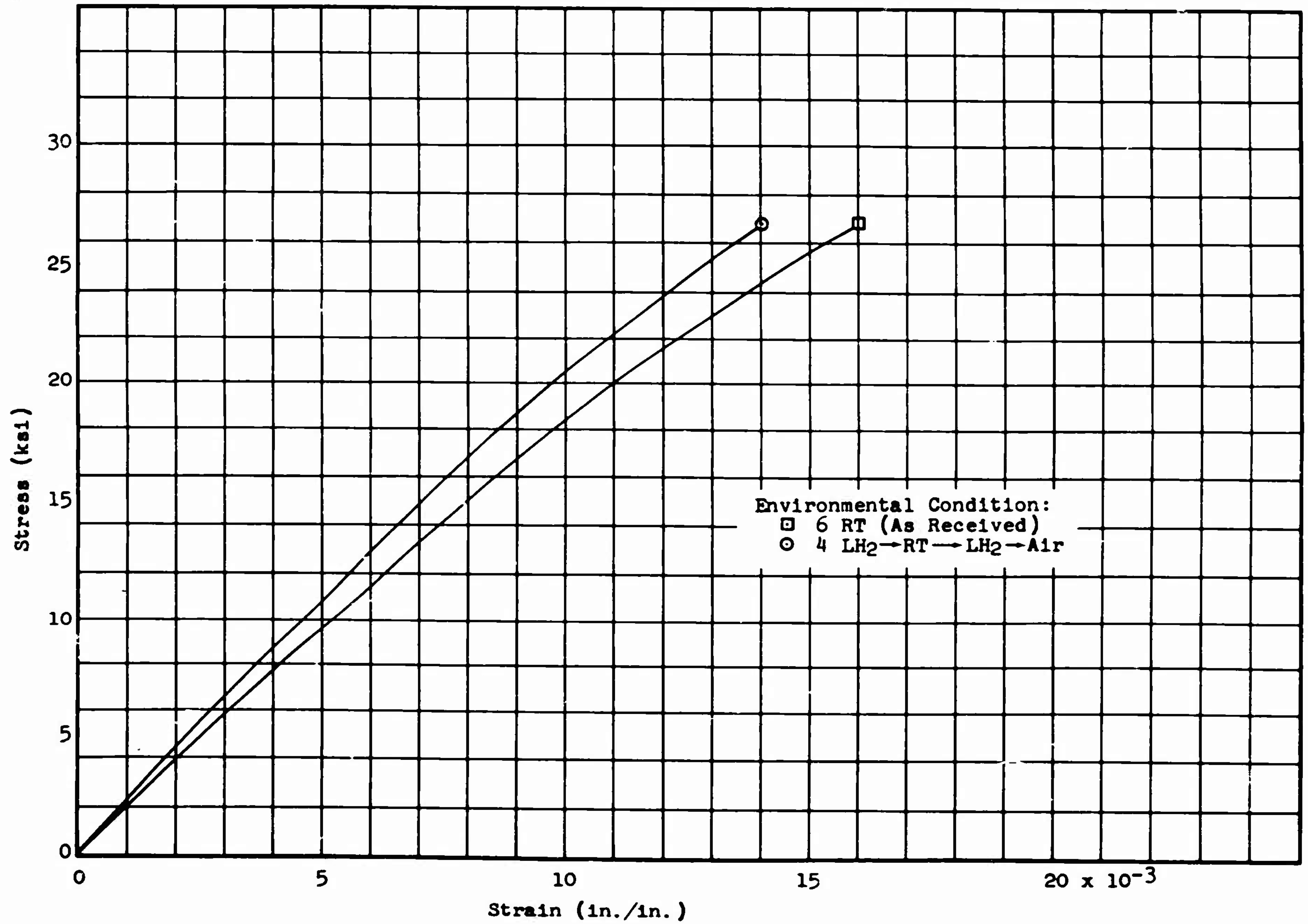

Figure 3-34 Armalon 510-L-128: Stress-Strain Curves of Control Specimens Showing Effect of Environmental Condition 4 vs 6

NPC 23,797

X - R A Y   D I F F R A C T I O N   S T U D Y

	SPECIMEN	X-RAY METHOD
Material	Armalon 510-L-128	Cu Tgt. Ni Fltr.
Form	1/8-in. Sheet	R. M. 16-1-4
Condition	Laminate	Slit 0.006

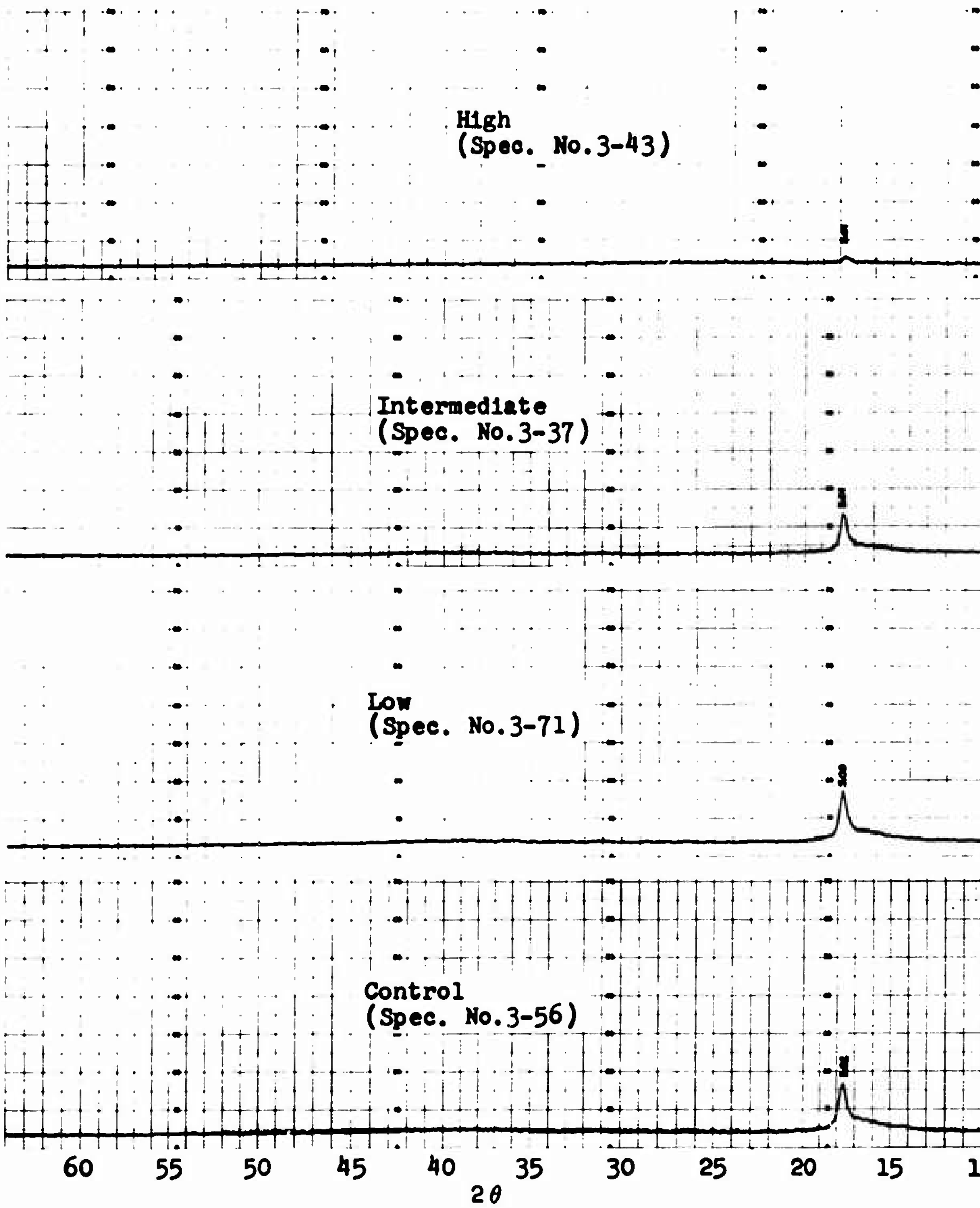

Figure 3-35 Armalon 510-L-128: Comparison of X-Ray Diffraction Data for a Typical Set of Specimens Exposed to Different Dose Levels and Tested at Environmental Condition 1

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3.2.4 Teflon FEP

A discrepancy was encountered in the testing of this material in that all specimens subjected to the high dose, and some at the intermediate dose, were damaged during the irradiation and hydrogen cycling and could not be tested. The damage is considered to have been caused by stress concentrations resulting from the riveted aluminum doublers. Therefore, no high-dose data are available for this material.

Representative fractures of this material, tested at both room and LH_2 temperature, are presented in Figures 3-36 and 3-37.

A comparison of the ultimate tensile strength at the different dose and environmental conditions is presented in Figure 3-38. These data indicate a similar damage trend as the previous three materials. Very little or no damage was detected in the low-dose specimens. Significant damage was detected at the intermediate level. As previously mentioned, the high-dose specimens could not be tested, but a visual inspection indicated nearly total damage. This can be seen in Figure 3-39.

A comparison of ultimate strain at the different test conditions is presented in Figure 3-40. These data indicate no change at the low-dose level but a very decided effect

at the intermediate level. The greatest effect was noted in the specimens tested at room temperature. For condition 4 the strain depreciated from 446% at the low-dose level to 161% at the intermediate-dose level. For condition 5 the damage was even greater, with a span of from 452% to 7.7%. This can possibly be explained by the theory that the primary cause of irradiation damage to Teflon is internal gas evolution. From this reasoning, the specimens tested at room temperature after being subjected to 300°F (cond. 5) would experience more damage than the specimens tested directly at room temperature (cond. 4).

A tabulation of all detailed mechanical property data is presented in Table 3-4. A statistical analysis of these data is included in Section 3.3.

Average stress-strain relationships are presented in Figures 3-41 through 3-45, showing the effects of dose level on specimens tested at environmental conditions 1 through 5, respectively. Stress-strain curves showing the comparison of control specimens tested at conditions 4 and 6 are shown in Figure 3-46.

The x-ray diffraction studies were made on specimens of all dose levels, even though no other high-dose data are reported. No radiation-induced change was indicated at any of the test conditions. A typical set of x-ray data is shown in Figure 3-47.

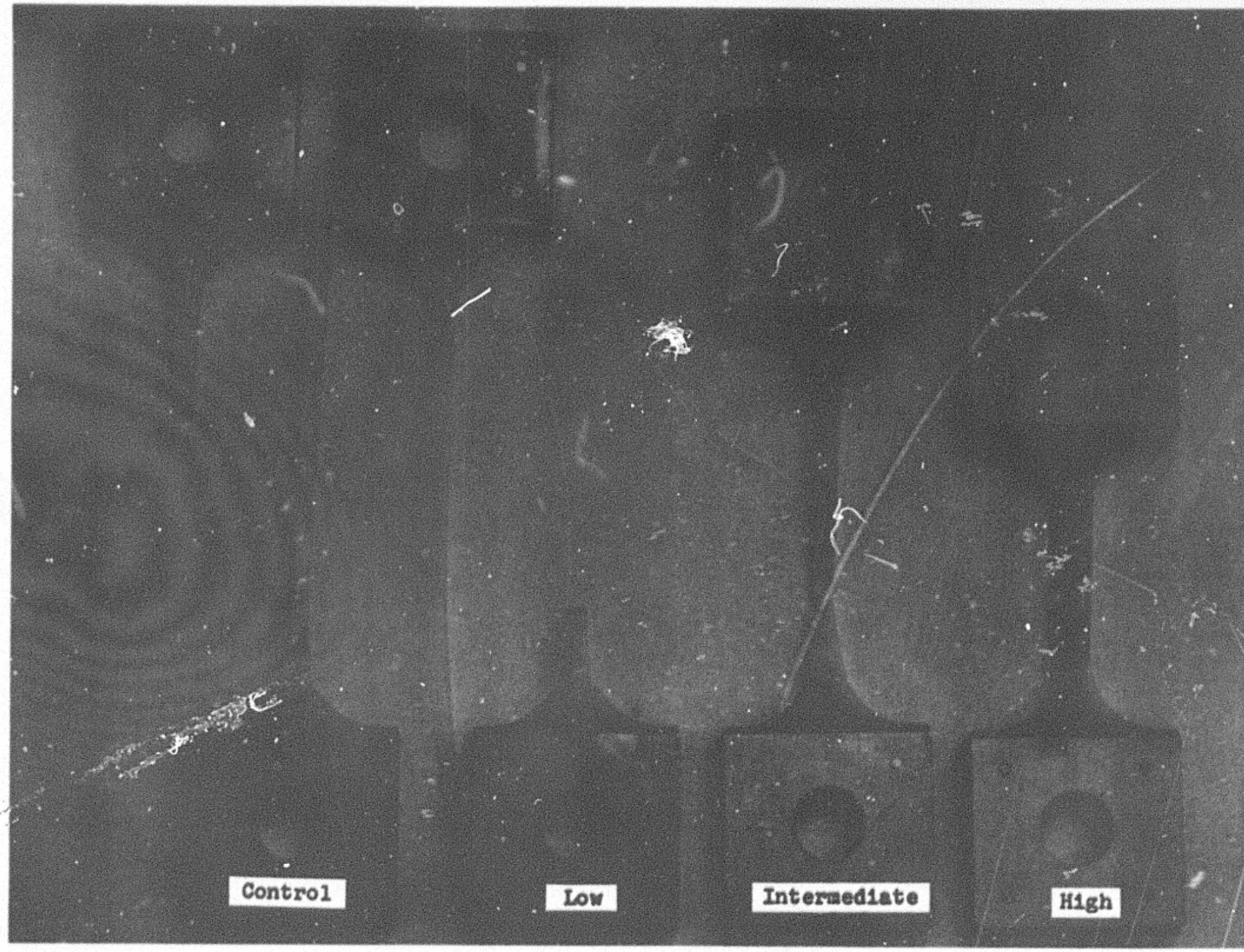
Table 3-4

Teflon FEP: Ultimate Tensile Strength and Elongation

Environmental Sequence	Test Temp	Control				Low Dose				Intermediate Dose				High Dose			
		Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)
Condition 1	LH_2	4-55	23.8	1	3.9	4-45	23.3	2	3.8	4-37	NO DATA	3	NO DATA	4-41	NO DATA	2	NO DATA
LH_2		4-56	25.8	1	4.0	4-69	22.9	1	3.8	4-61		3		4-65		3	
		4-79	23.6	1	3.8	4-47	22.3	2	3.3	4-39		3		4-43		3	
		4-80	22.3	1	3.7	4-71	22.1	1	3.8	4-63		3		4-67		3	
		Avg/σ:	23.9/1.7		3.85/0.14	Avg/σ:	22.7/0.6		3.7/0.24								
Condition 2	LH_2	4-57	23.9	1	4.1	4-46	22.9	1	3.6	4-38	12.3	3	1.8	4-42	NO DATA	2	NO DATA
LH_2→GHe→LH_2		4-58	24.1	1	3.9	4-48	20.6	2	3.3	4-40	17.6	3	2.6	4-66		3	
		4-81	23.8	1	3.7	4-70	22.8	1	3.9	4-62	No Data	3	No Data	4-44		3	
		4-82	24.2	1	3.8	4-72	22.8	1	3.8	4-64	15.6	3	2.4	4-68		3	
		Avg/σ:	24.0/0.2		3.9/0.19	Avg/σ:	22.3/1.1		3.6/0.15	Avg/σ:	15.2/3.1		2.3/0.47				
Condition 3	LH_2	NOT TESTED				4-53	23.8	2	3.8	4-49	14.0	2	2.2	4-51	NO DATA	4	NO DATA
LH_2→GHe→LH_2 →Air→LH_2						4-54	23.9	1	3.7	4-50	19.7	3	2.8	4-52		4	
						4-77	25.3	1	3.8	4-73	22.3	3	3.3	4-75		4	
						4-78	22.4	1	3.6	4-74	20.5	1	3.3	4-76		4	
						Avg/σ:	23.9/1.4		3.7/0.10	Avg/σ:	19.1/4.0		2.9/0.53				
Condition 4	Room Temp	4-28	3.8	1	468.7	4-9	2.8	1	452.7	4-1	1.77	1	147.8	4-5	NO DATA	4	NO DATA
LH_2→GHe→LH_2 →Air		4-29	3.4	1	437.8	4-10	3.2	1	471.7	4-2	1.45	1	136.6	4-6		4	
		4-30	3.7	1	466.4	4-11	2.8	1	433.1	4-3	1.77	1	166.3	4-7		4	
		4-31	3.5	1	448.0	4-12	3.0	1	425.5	4-4	1.78	1	192.9	4-8		4	
		Avg/σ:	3.6/0.20		455.2/15.0	Avg/σ:	3.0/0.18		445.8/22.4	Avg/σ:	1.69/0.16		160.9/27.3				
Condition 5	Room Temp	NOT TESTED				4-21	2.9	1	427.7	4-13	1.37	1	5.0	4-17	NO DATA	4	NO DATA
LH_2→GHe→LH_2 →Air→300°F→Air						4-22	3.2	1	468.2	4-14	2.27	1	10.5	4-18		4	
						4-23	3.1	1	449.4	4-15	No Data	3	No Data	4-19		4	
						4-24	3.2	1	464.5	5-16	No Data	3	No Data	4-20		4	
						Avg/σ:	3.1/0.15		452.2/17.9	Avg/σ:	1.82/0.8		7.7/4.9				
Condition 6	Room Temp	4-32	3.6	1	498.7	NOT TESTED				NOT TESTED				NOT TESTED			
As Received		4-33	3.9	1	473.2												
		4-34	4.0	1	489.0												
		4-35	4.3	1	519.8												
		Avg/σ:	4.0/0.34		495.2/22.6												

*Type of Break

1 - Gage length
2 - Point of tangency
3 - Rivets and/or grip
4 - Static
5 - Combination of delamination, tangency, and/or shear



NPC 23,559
31-8514

Figure 3-36 Teflon FEP: Fractured Specimens Pulled at Room Temperature after Exposure to Low, Intermediate, and High Gamma Doses

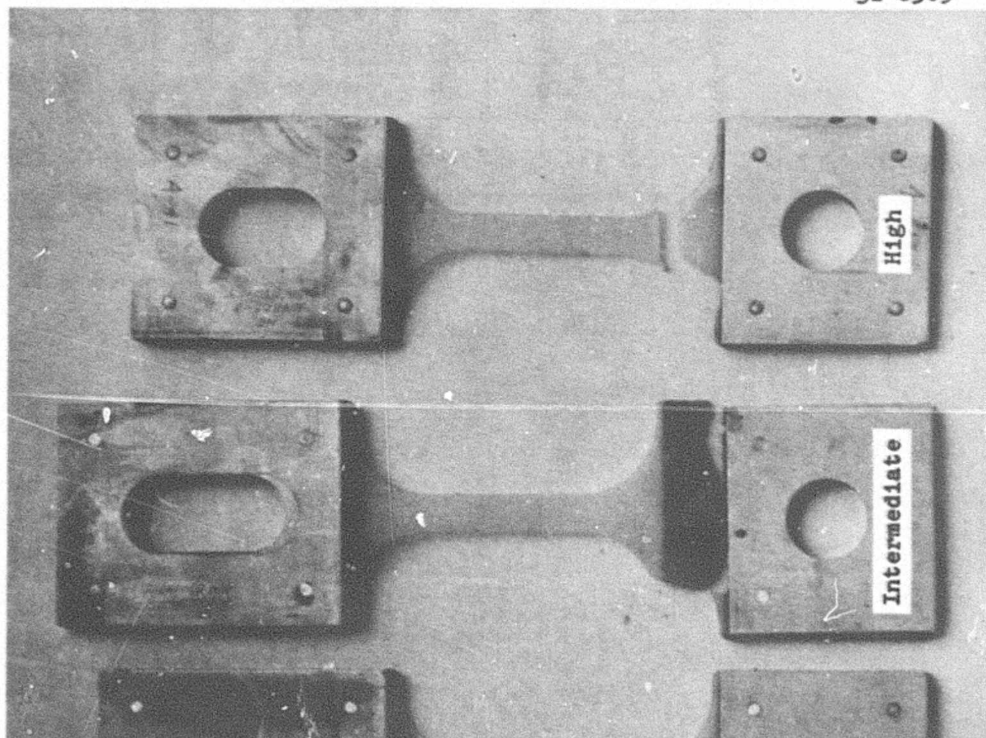
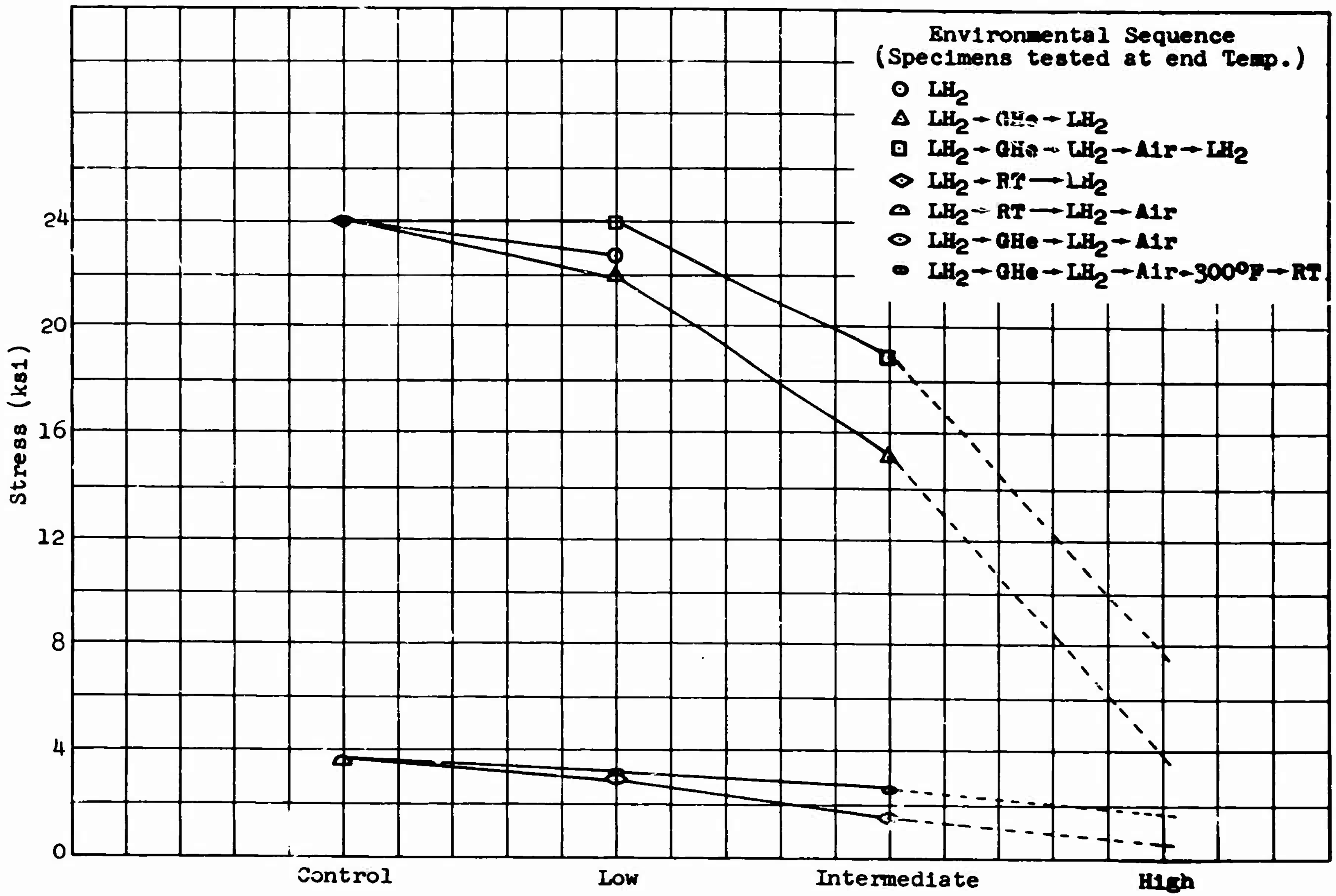


Figure 3-37 Teflon FEP: Fractured Specimens Pulled at LH_2 Temperature after Exposure to Low, Intermediate, and High Gamma Doses



NPC 23,567

Figure 3-38 Teflon FEP: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Tensile Strength

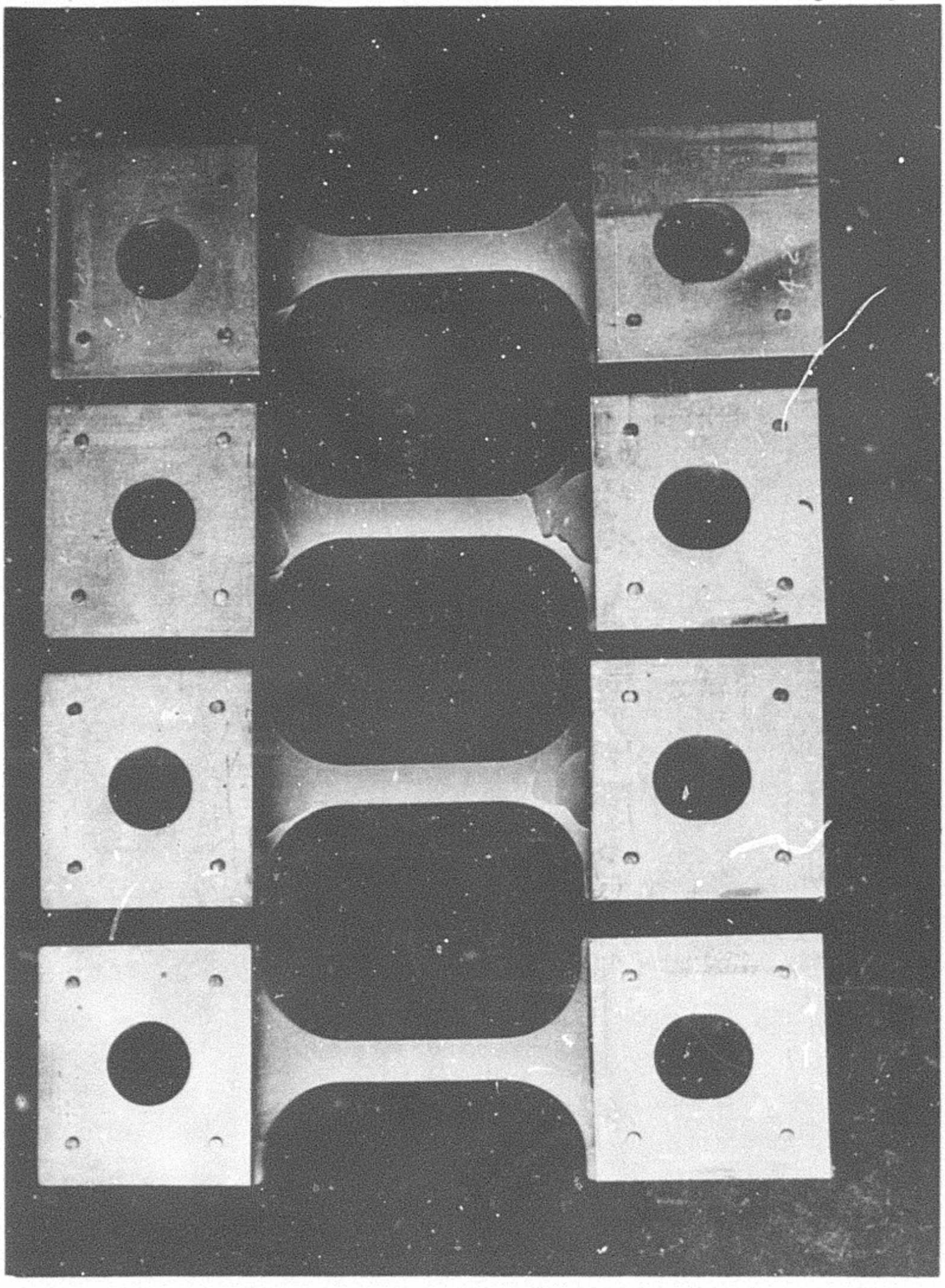


Figure 3-39 Teflon FEP: Four Typical Specimens From the High-Dose Test Assembly, Showing Static Failure

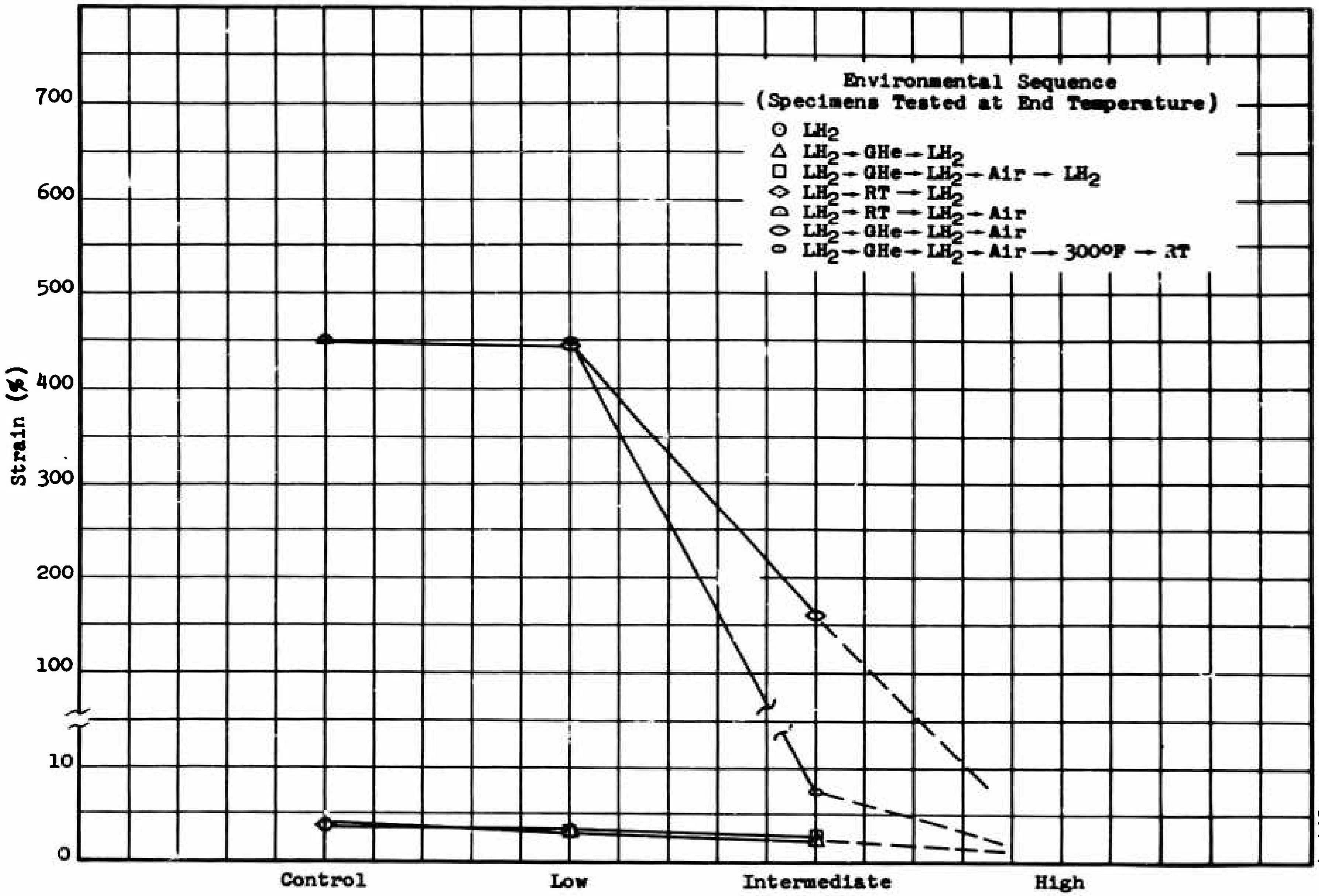


Figure 3-40 Teflon FEP: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Strain

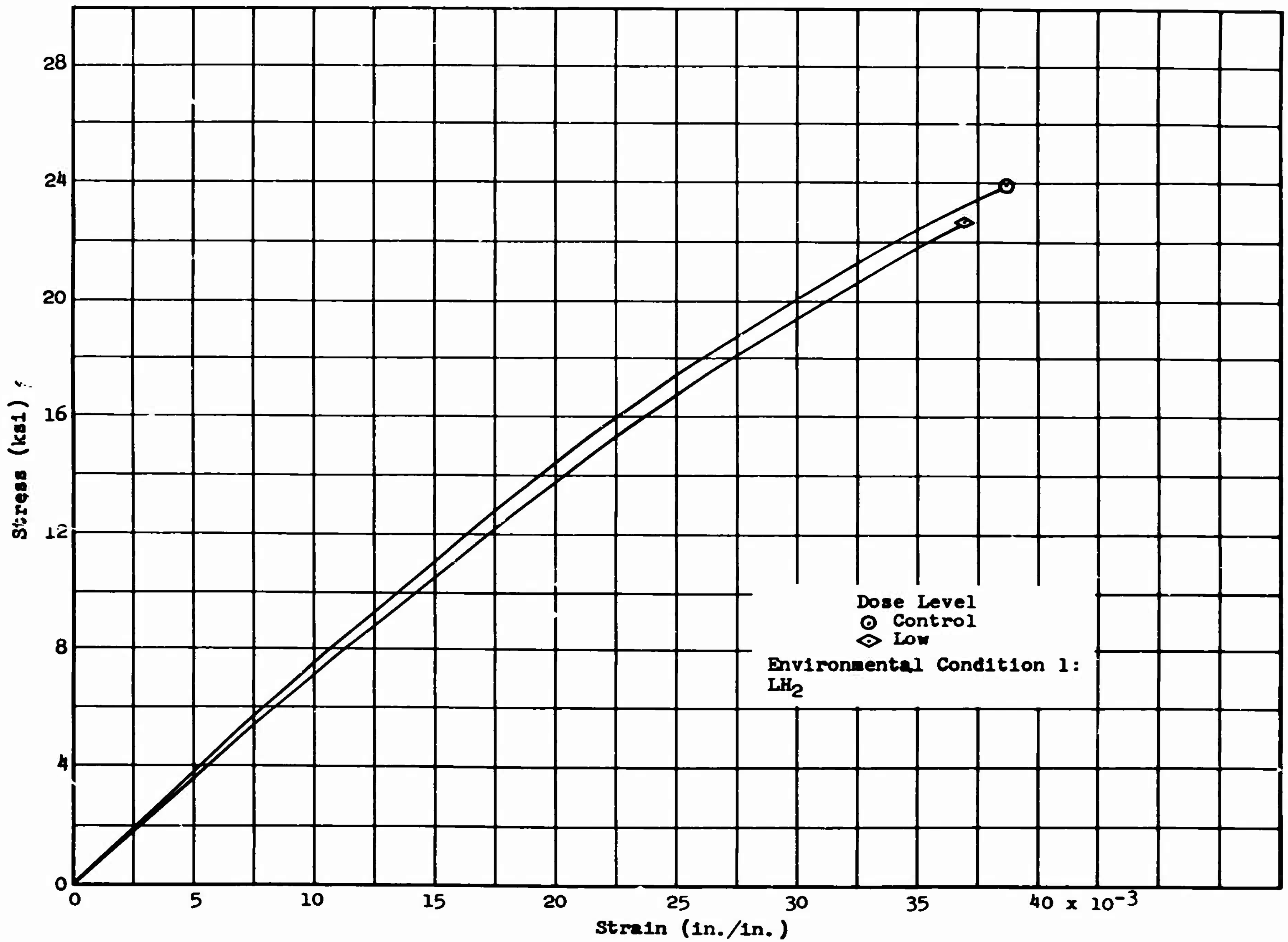


Figure 3-41 Teflon FEP: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 1

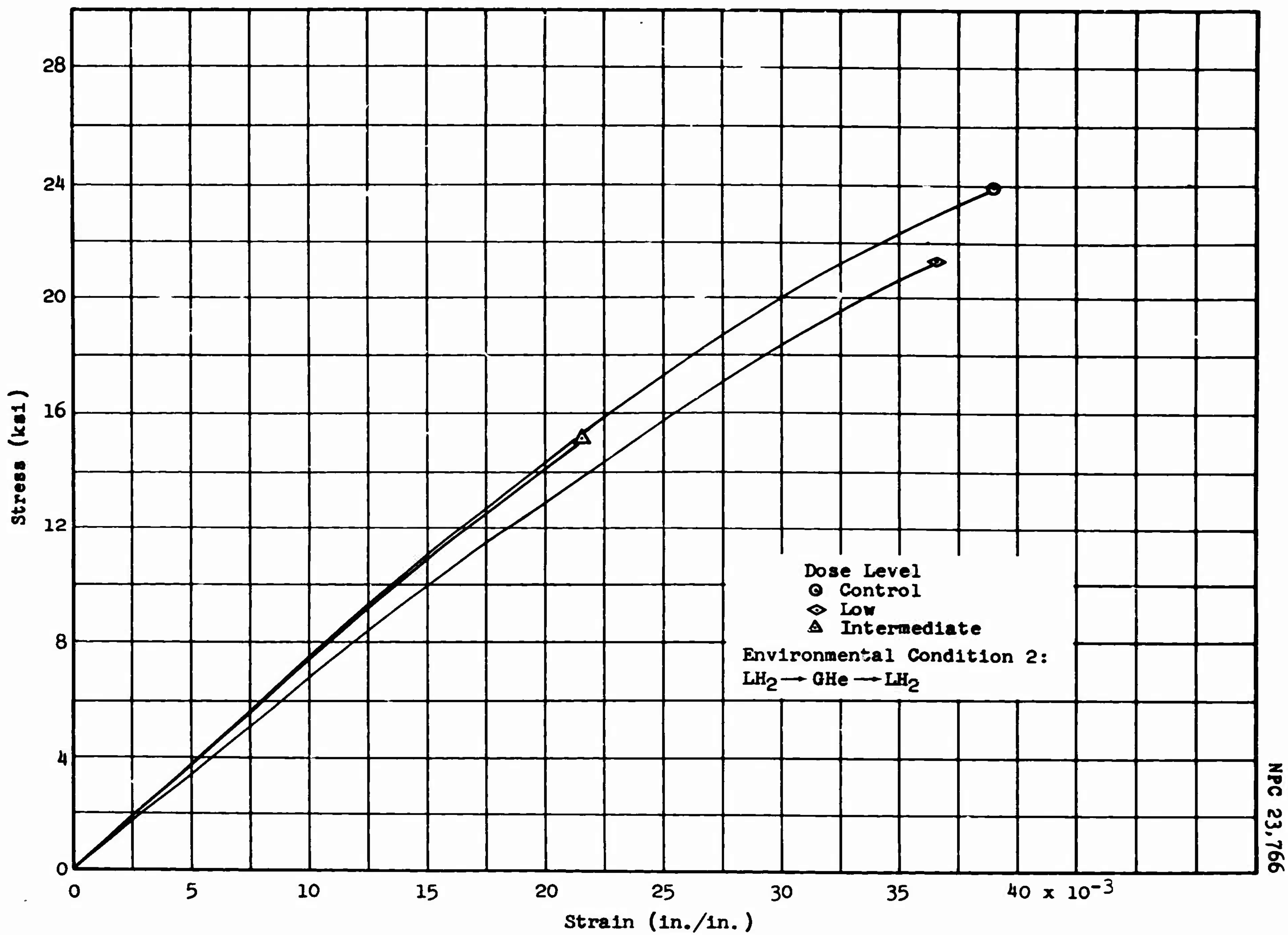


Figure 3-42 Teflon FEP: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 2

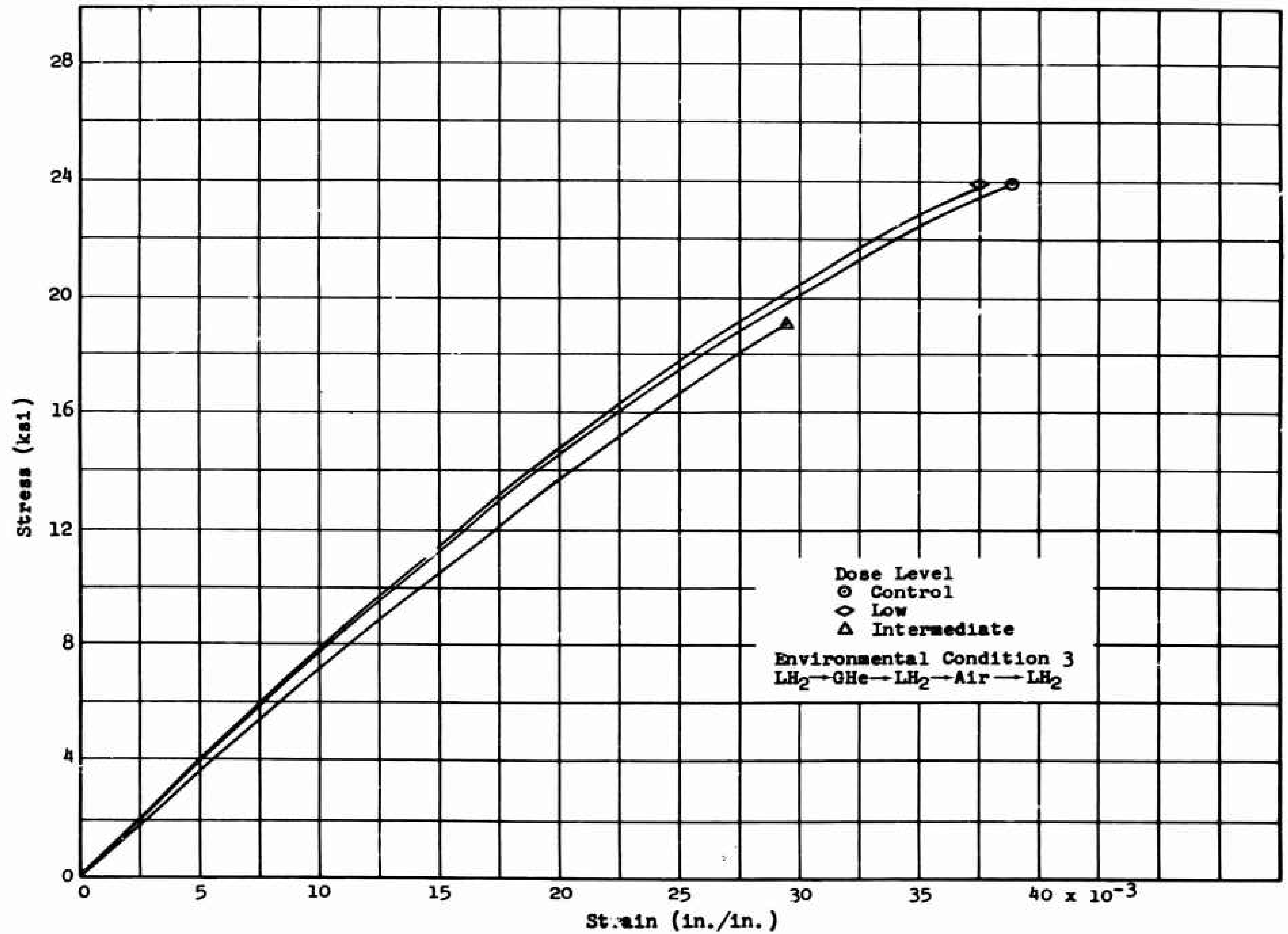


Figure 3-43 Teflon FEP: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 3

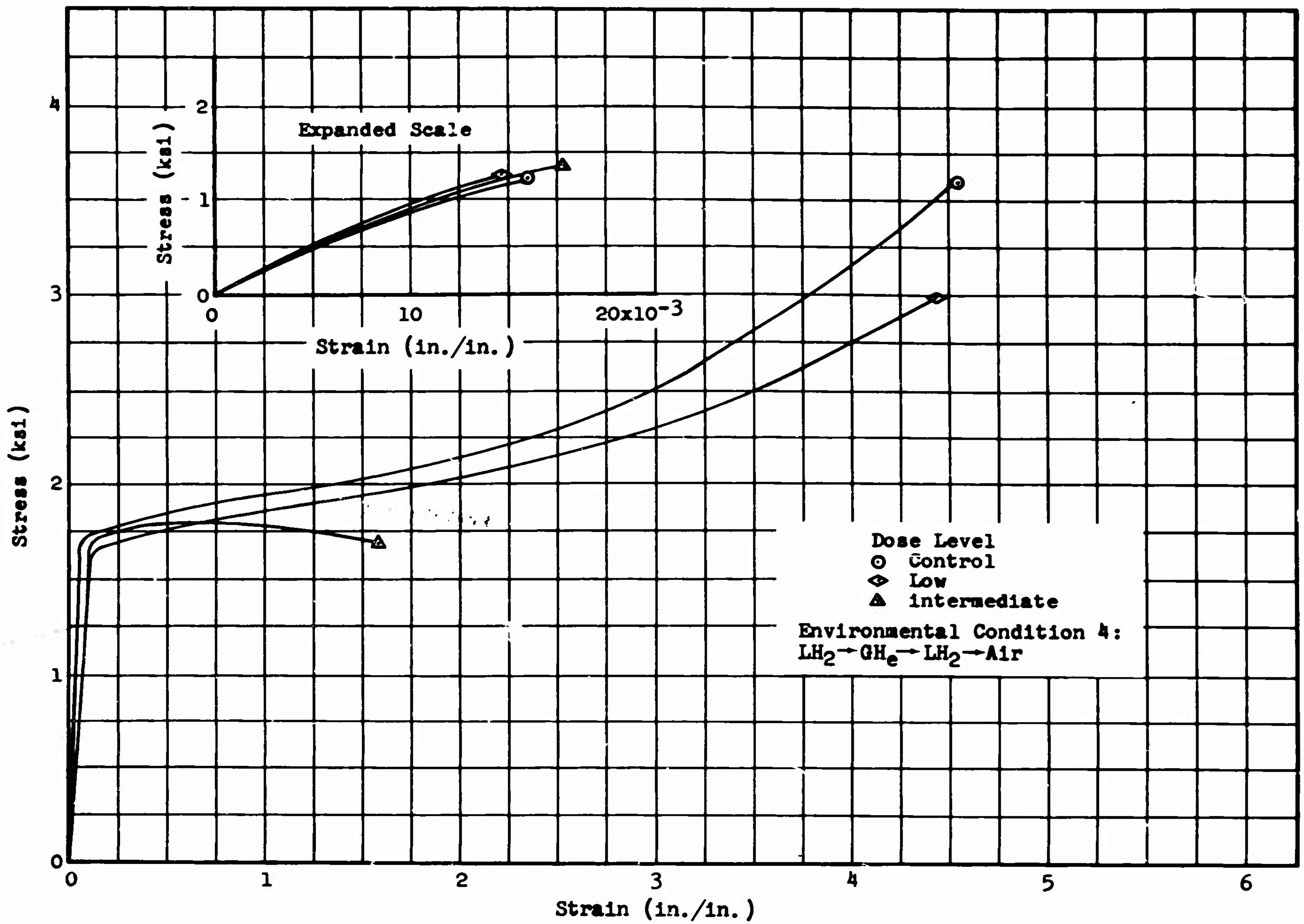


Figure 3-44 Teflon FEP: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 4

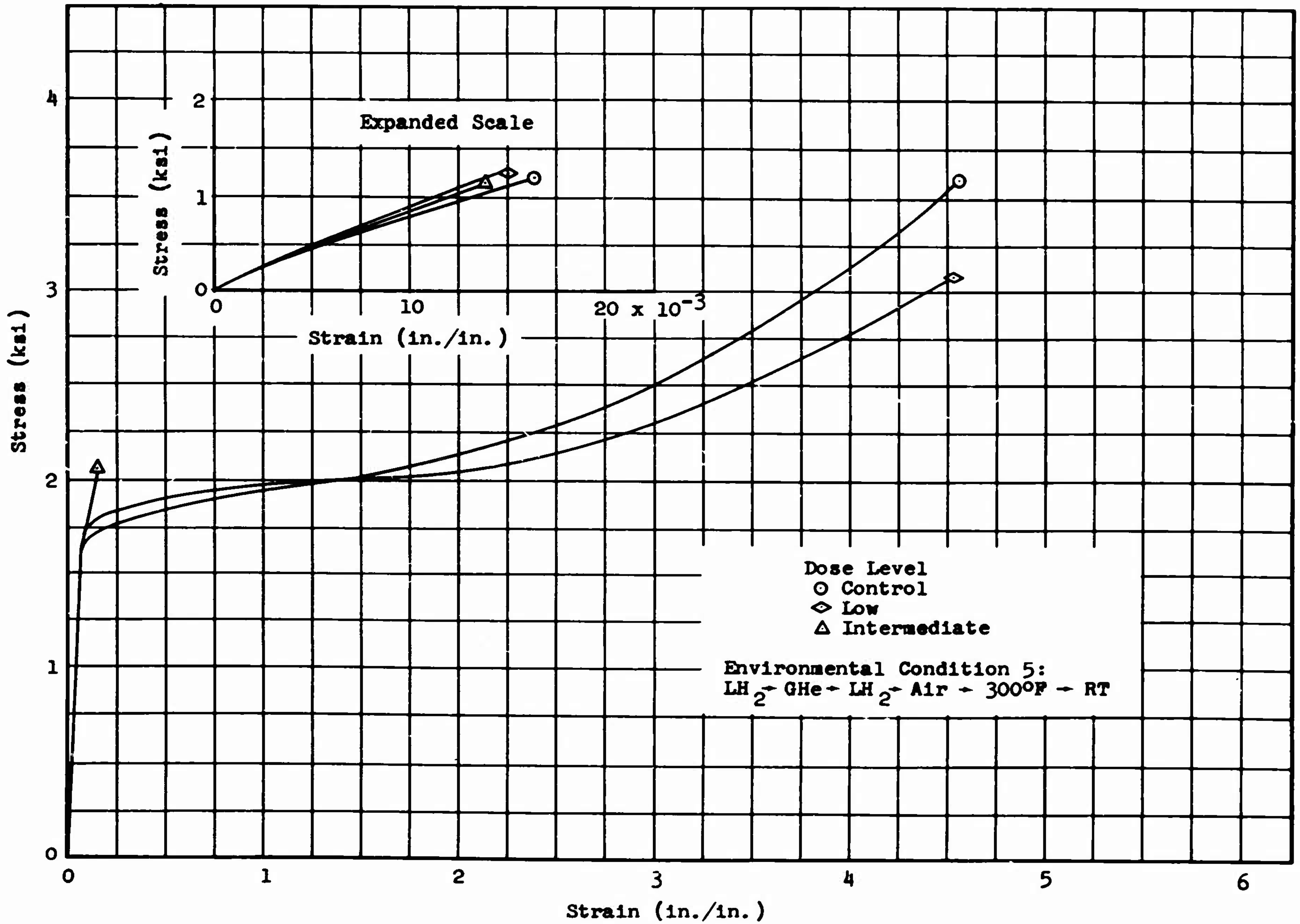


Figure 3-45 Teflon FEP: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 5

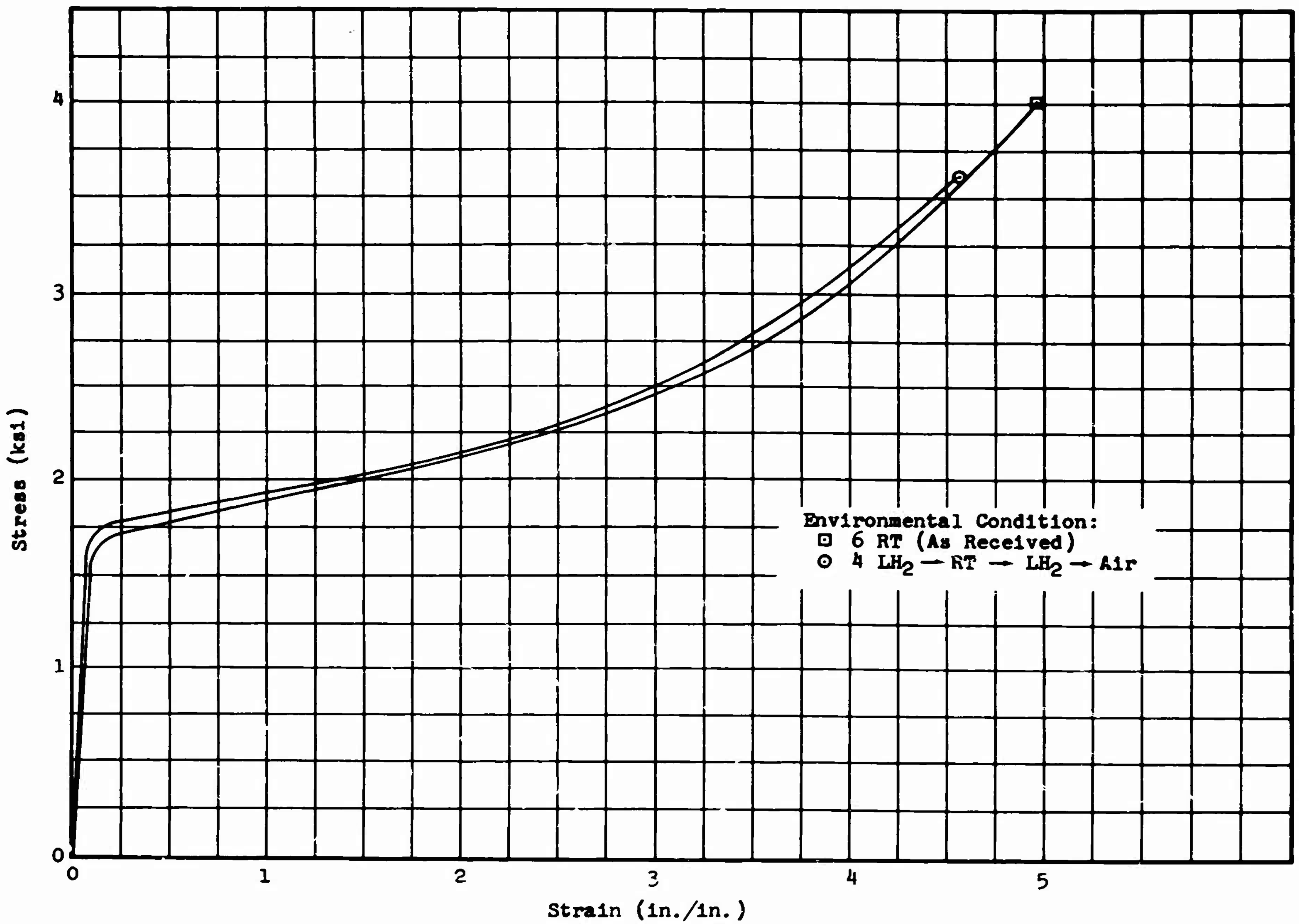


Figure 3-46 Teflon FEP: Stress-Strain Curves of Control Specimens Showing Effect of Environmental Condition 4 vs 6

X-RAY DIFFRACTION STUDY

SPECIMEN		X-RAY METHOD
Material	Teflon FEP	Cu Tgt. Ni Fltr.
Form	1/8-in. Sheet	R.M. 16-1-4
Condition	Molded	Slit 0.006

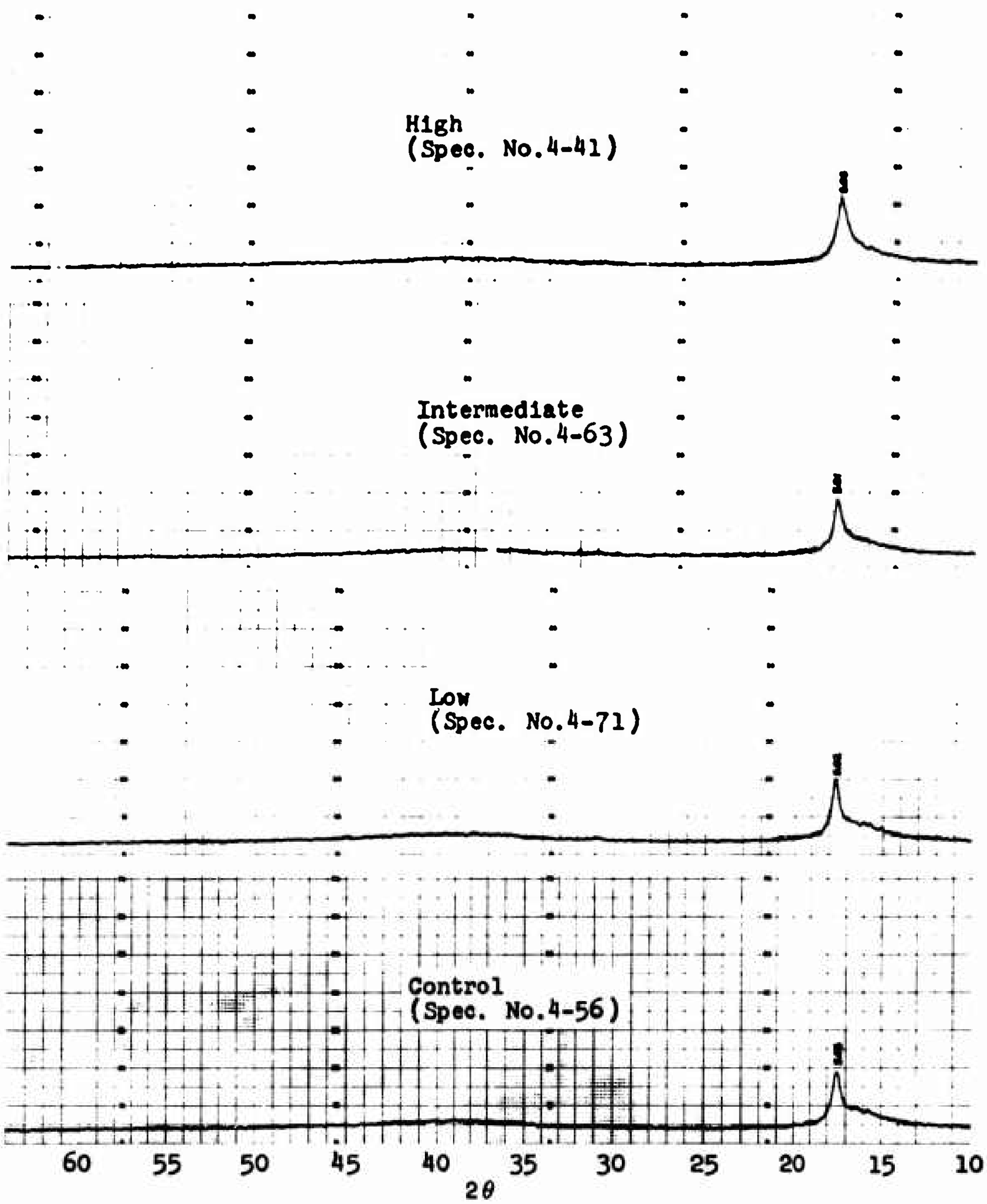


Figure 3-47 Teflon FEP: Comparison of X-Ray Diffraction Data for a Typical Set of Specimens Exposed to Different Dose Levels and Tested at Environmental Condition 1

3.2.5

Superpolymer SP-3

3.2.5 Superpolymer SP-3

All specimens of this material were tested satisfactorily with good results. The data were found to be very consistent. This material was found to exhibit an increase in strength when tested at LH_2 temperature relative to room temperature, but the elongation seemed to be relatively non-temperature dependent.

Representative fractures of this material, tested at room and LH_2 temperatures, are presented in Figures 3-48 and 3-49.

Comparisons of ultimate tensile strength and ultimate strain at the different environmental conditions are presented in Figures 3-50 and 3-51, respectively. From these data it can be seen that the SP-3 material was damage-free at the dose levels achieved in this test. However, some increase in data scatter is indicated with an increase in dose. A tabulation of detailed data is shown as Table 3-5. A statistical analysis of the data is contained in Section 3.3.

Average stress-strain relationships are presented in Figures 3-52 through 3-55, showing the effects of dose level on specimens tested at environmental conditions 1, 3, 4, and 5, respectively. Stress-strain curves showing a comparison of control specimens tested at conditions 4 and 6 are shown in Figure 3-56.

The x-ray diffraction studies showed no change at any of the conditions. A typical set of x-ray data is shown in Figure 3-57.

Table 3-5

Superpolymer SP-3: Ultimate Tensile Strength and Elongation

Environmental Sequence	Test Temp	Control				Low Dose				Intermediate Dose				High Dose			
		Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)	Specimen No.	Stress (ksi)	Type of Break*	Strain (%)
Condition 1		5-25	15.8	1	2.4	5-9	14.5	1	2.2	5-1	20.6	1	2.8	5-5	15.0	1	1.9
LH_2	LH_2	5-26	15.5	1	2.2	5-10	18.0	1	2.9	5-2	13.6	1	1.9	5-6	17.3	1	2.6
		5-27	17.1	1	2.4	5-11	15.9	1	2.4	5-3	17.3	1	2.3	5-7	14.6	1	2.1
		5-28	17.1	2	2.6	5-12	16.0	1	2.3	5-4	20.0	2	2.8	5-8	18.1	2	2.4
		Avg/σ:	16.3/0.8		2.4/0.19	Avg/σ:	16.1/1.7		2.4/0.34	Avg/σ:	17.9/3.4		2.5/0.44	Avg/σ:	16.3/1.7		2.2/0.34
Condition 2		5-29	16.9	2	3.8	NOT TESTED				NOT TESTED				NOT TESTED			
LH_2-GHe-LH_2	LH_2	5-30	17.4	2	3.7												
		5-31	11.5	1	2.5												
		5-32	16.2	1	3.3												
		Avg/σ:	15.5/2.9		3.3/0.63												
Condition 3		NOT TESTED				5-21	15.4	1	No Data	5-13	18.6	1	4.4	5-17	16.8	1	3.4
LH_2-GHe-LH_2 -Air-LH_2	LH_2					5-22	17.4	1	3.5	5-14	15.1	2	3.5	5-18	15.6	1	3.6
						5-23	18.3	1	3.3	5-15	15.5	1	3.4	5-19	15.1	1	4.3
						5-24	15.9	1	3.5	5-16	19.5	2	4.4	5-20	16.4	1	3.1
						Avg/σ:	16.8/1.4		3.4/0.12	Avg/σ:	17.2/2.1		3.9/0.49	Avg/σ:	16.0/0.8		3.6/0.58
Condition 4		5-36	10.0	1	4.2	5-52	10.7	1	4.6	5-44	12.4	1	6.7	5-48	13.1	1	7.2
LH_2-GHe-LH_2 -Air	Room Temp	5-37	10.5	1	4.4	5-53	12.1	1	5.8	5-45	9.96	1	3.8	5-49	10.8	2	4.6
		5-38	10.3	1	4.5	5-54	12.3	1	6.5	5-46	12.9	1	7.4	5-50	8.8	1	3.0
		5-39	11.0	1	4.5	5-55	12.3	1	6.0	5-47	11.3	1	5.1	5-51	11.9	1	5.6
		Avg/σ:	10.5/0.5		4.4/0.15	Avg/σ:	11.9/0.8		5.7/0.92	Avg/σ:	11.6/1.4		5.8/1.7	Avg/σ:	11.5/2.1		5.1/2.0
Condition 5		NOT TESTED				5-60	10.9	1	4.2	5-56	13.1	1	6.4	5-64	12.7	1	6.4
LH_2-GHe-LH_2 -Air-300°F-Air	Room Temp					5-61	11.7	1	5.0	5-57	11.7	1	5.0	5-56	11.4	2	4 4.8
						5-62	12.8	1	6.4	5-58	12.1	1	4.9	5-66	8.8	2	2.9
						5-63	11.5	1	5.0	5-59	10.1	1	3.7	5-67	12.0	1	5.7
						Avg/σ:	11.7/0.9		5.2/0.11	Avg/σ:	11.8/1.5		5.0/1.3	Avg/σ:	11.2/1.9		5.0/1.7
Condition 6		5-40	10.2	1	4.0	NOT TESTED				NOT TESTED				NOT TESTED			
As Received	Room Temp	5-41	10.7	1	4.6												
		5-42	12.3	1	6.6												
		5-43	10.6	1	4.5												
		Avg/σ:	11.0/1.0		4.9/1.3												

*Type of Break

1 - Gage length
2 - Point of tangency
3 - Rivets and/or grip
4 - Static
5 - Combination of delamination, tangency, and/or shear

NPC 23,561
31-8513

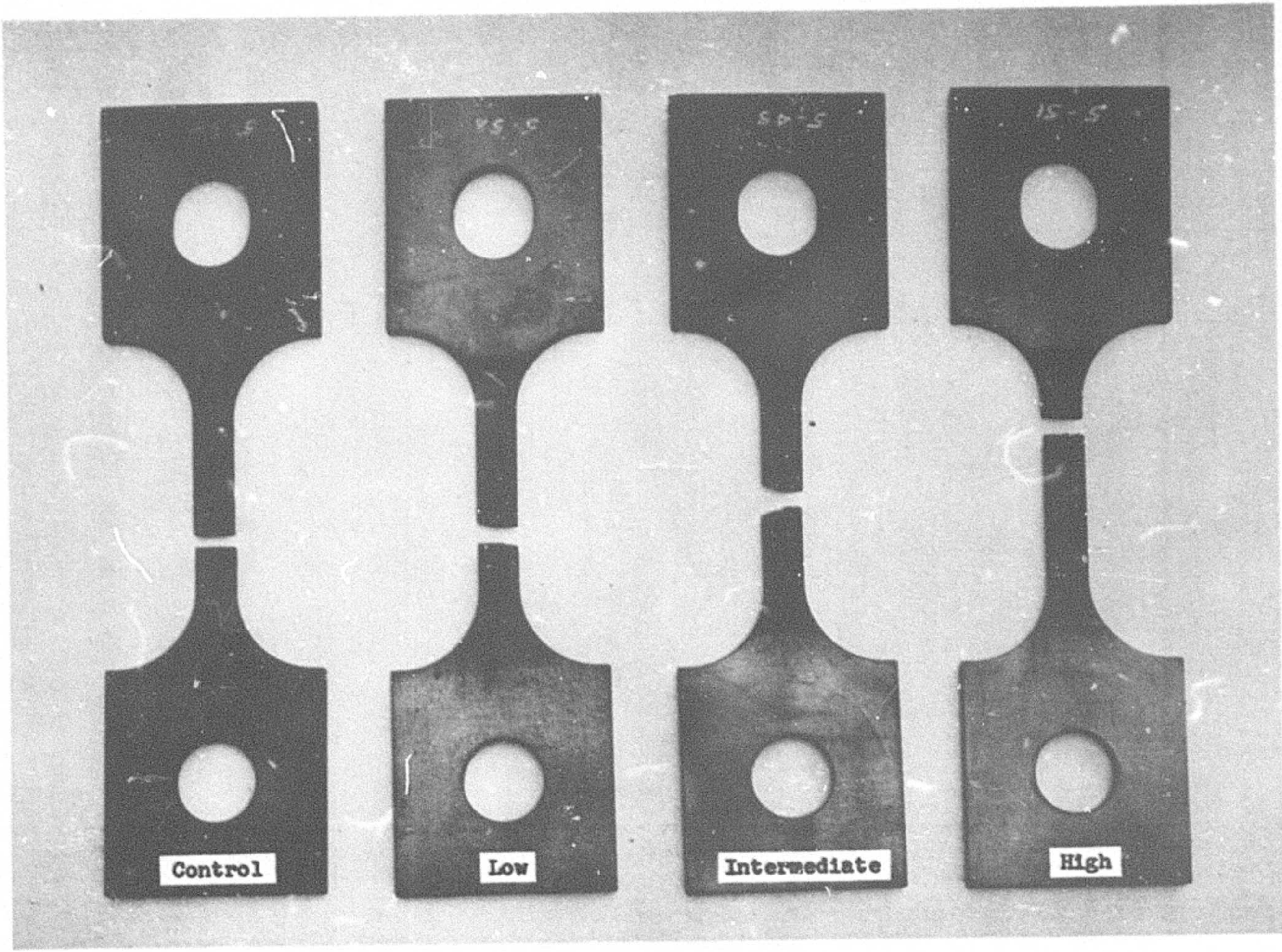


Figure 3-48 Superpolymer SP-3: Fractured Specimens Pulled at Room Temperature after Exposure to Low, Intermediate, and High Gamma Doses

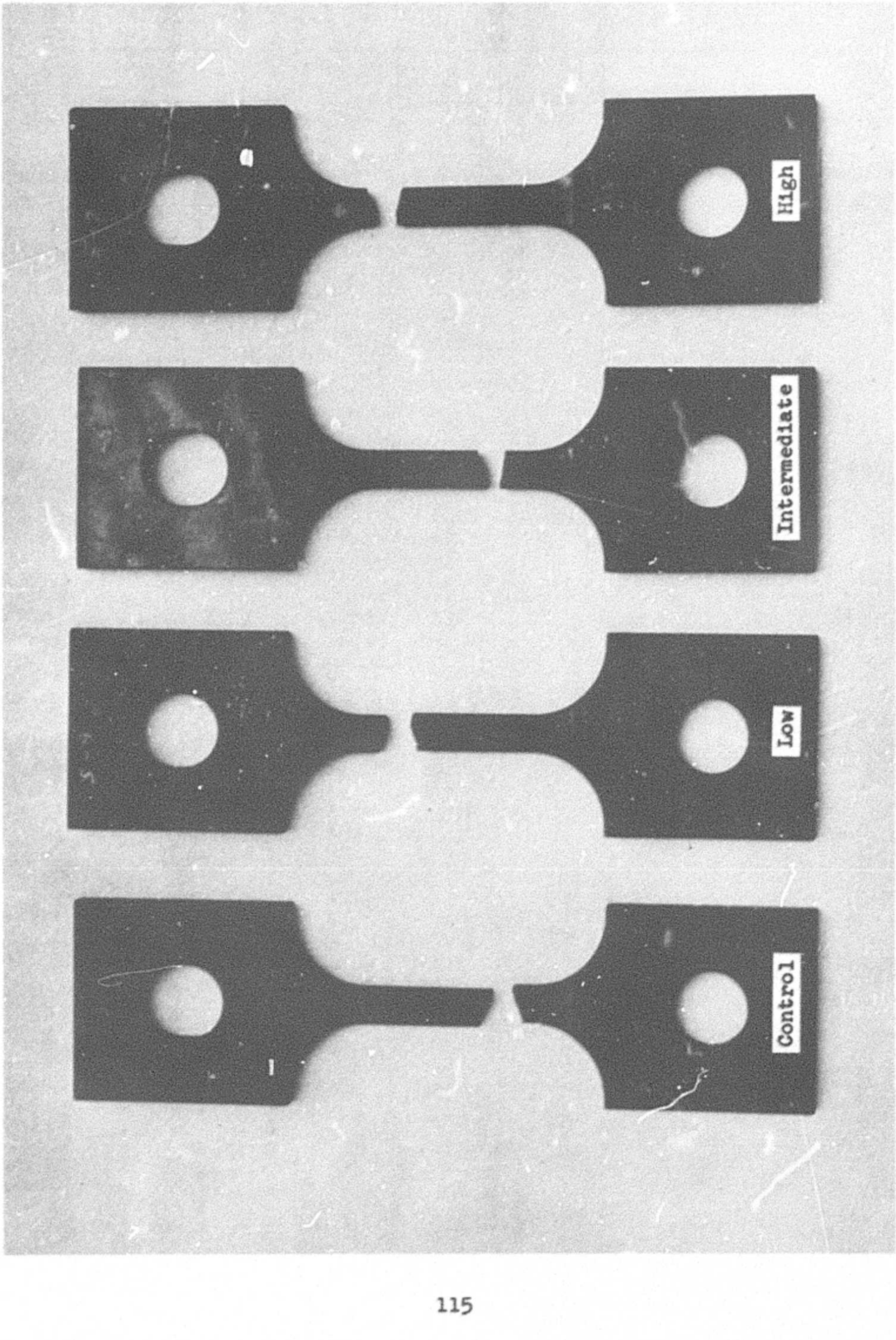


Figure 4-49 Superpolymer SP-3: Fractured Specimens Pulled at LH_2 Temperature after Exposure to Low, Intermediate, and High Gamma Doses

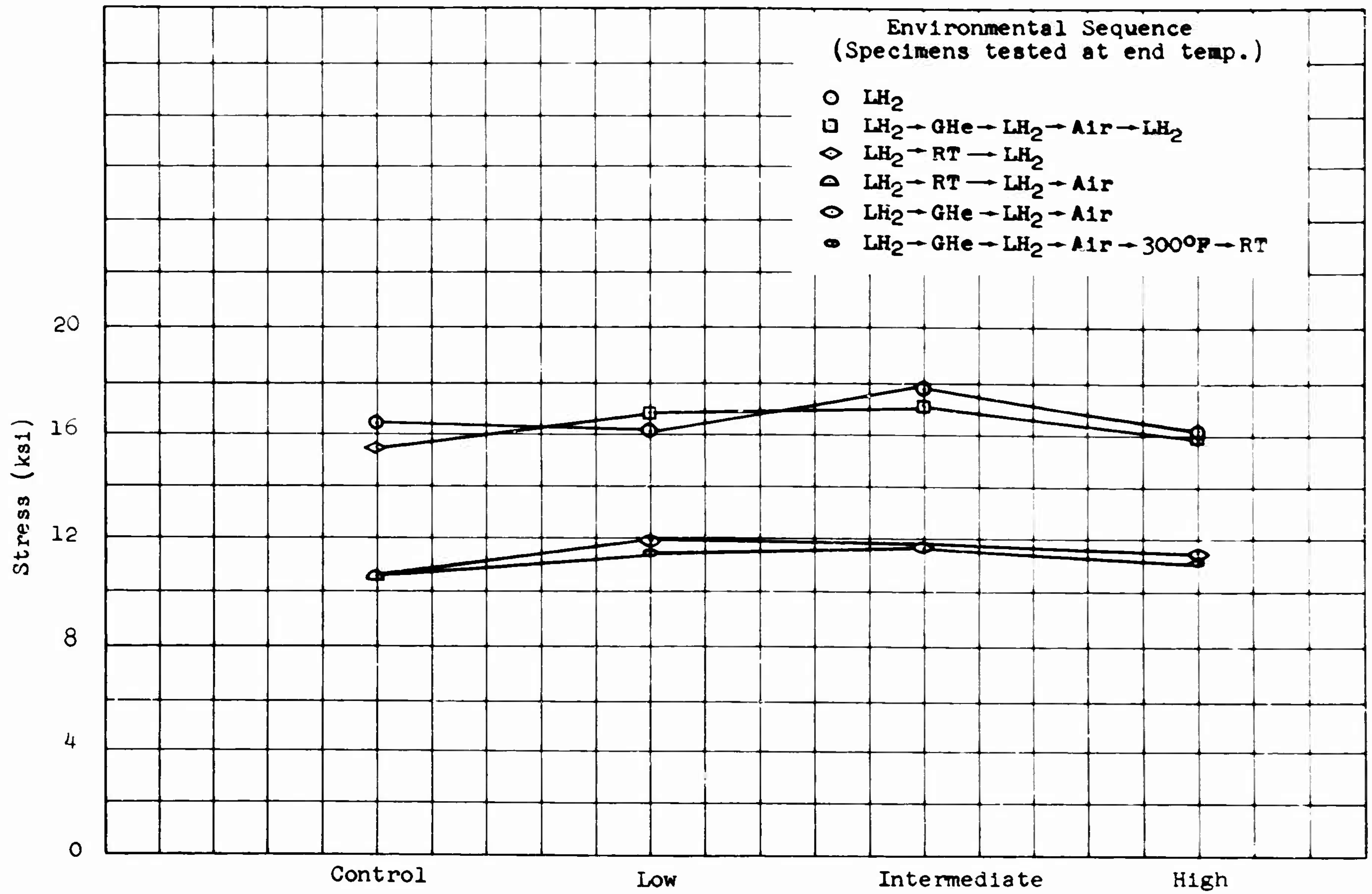


Figure 3-50 Superpolymer SP-3: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Tensile Strength

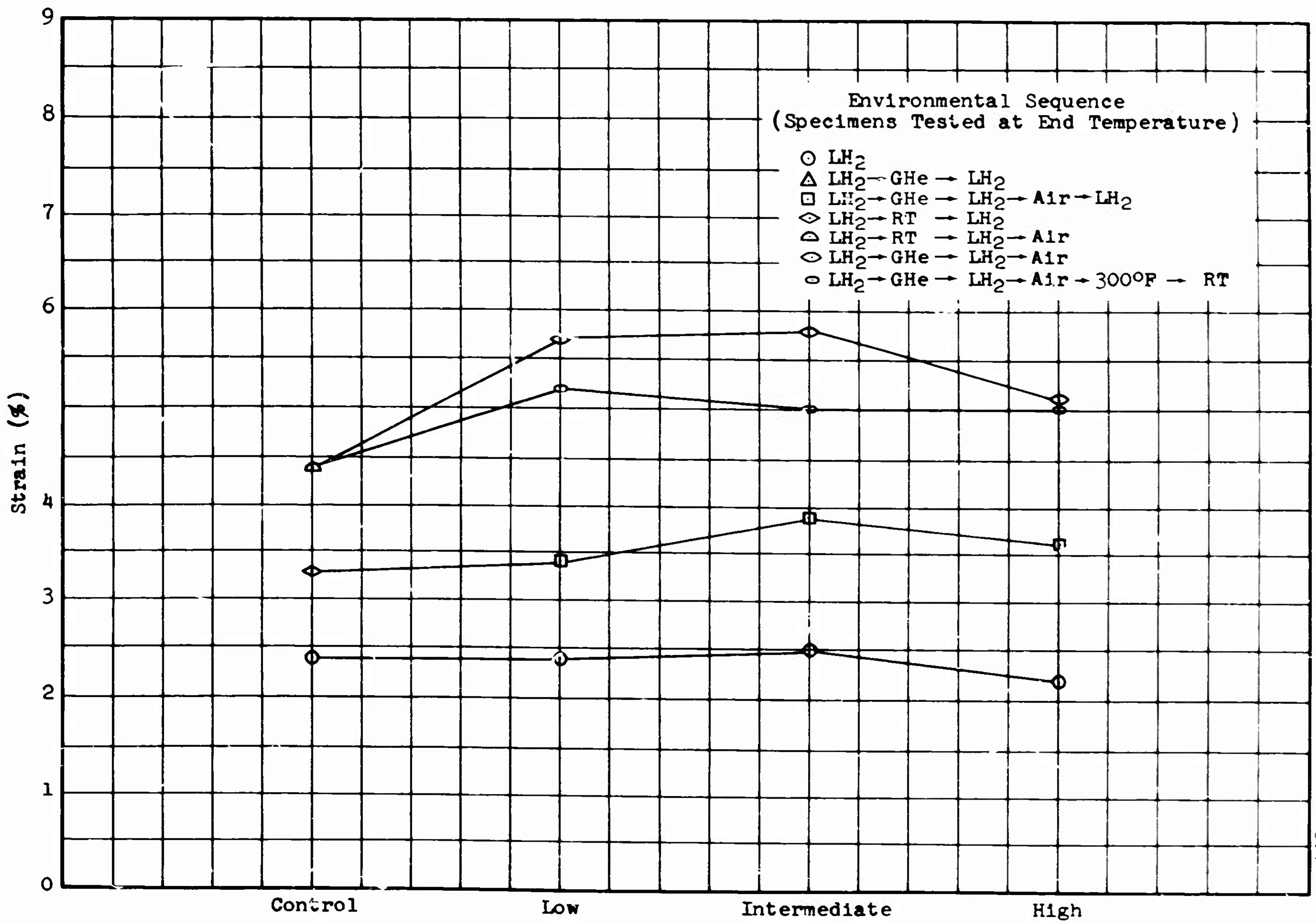


Figure 3-51 Superpolymer SP-3: Effect of Gamma Dose and Postirradiation Environmental Sequence on Ultimate Strain

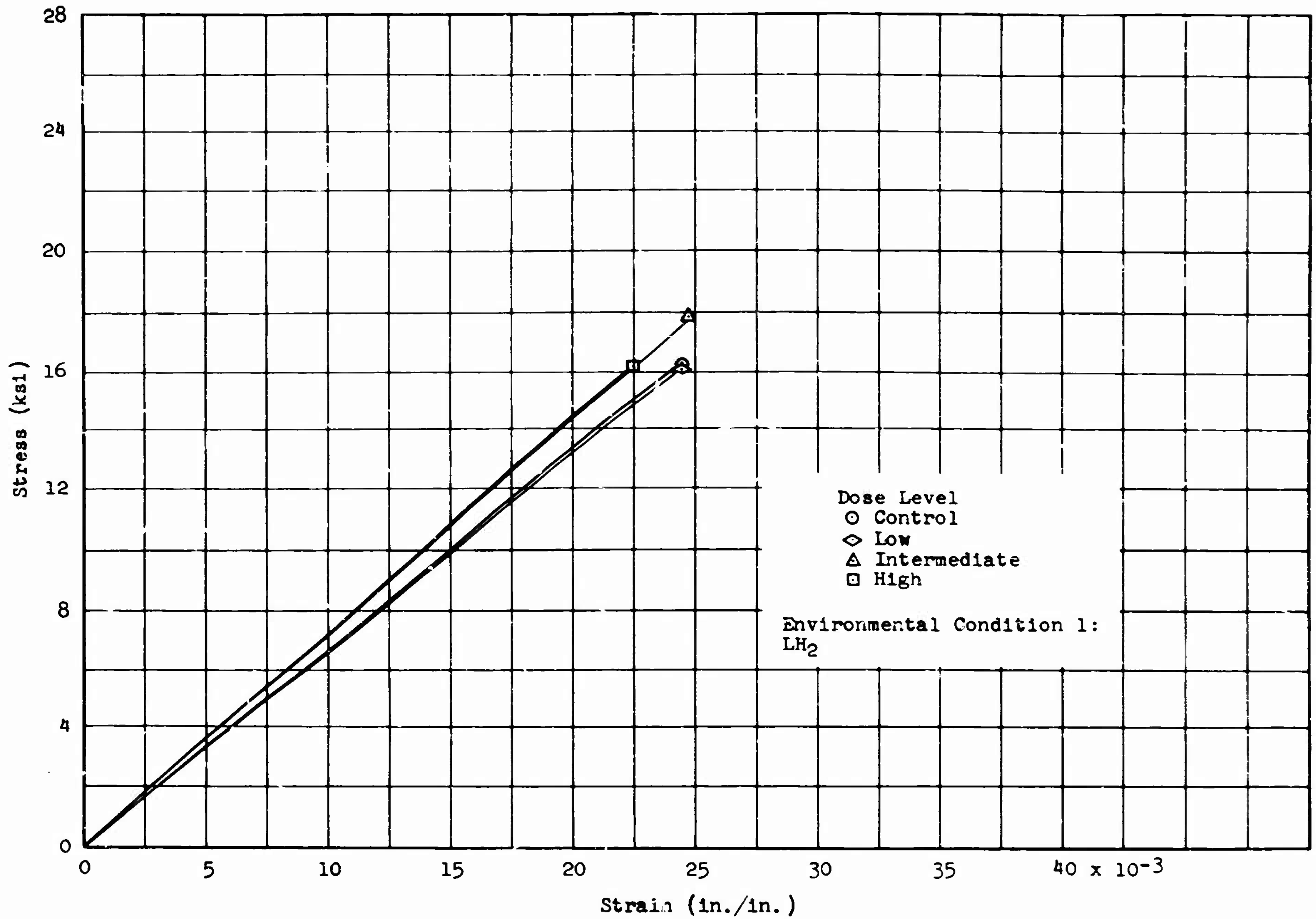


Figure 3-52 Superpolymer SP-3: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 1

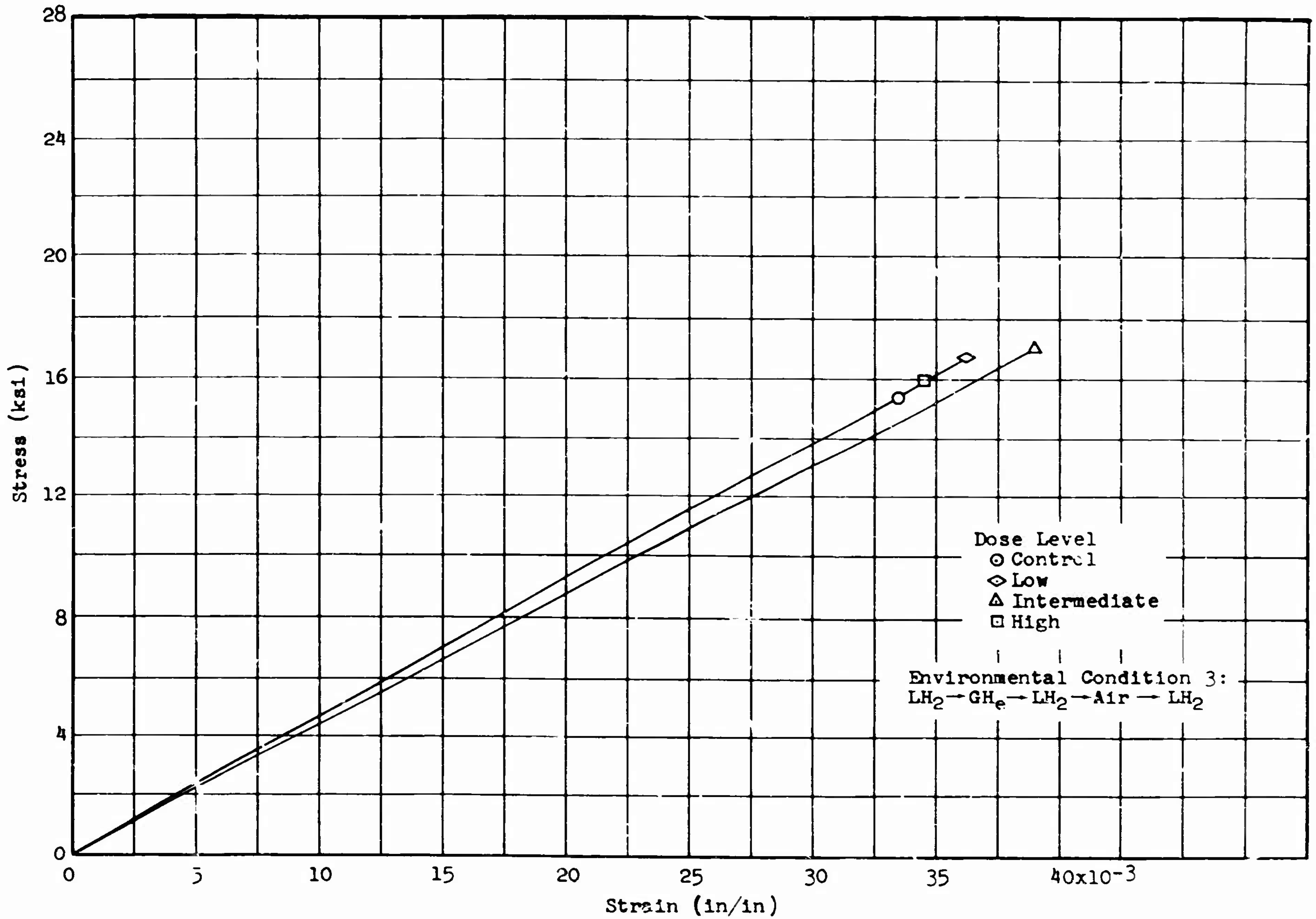


Figure 3-53 Superpolymer SP-3: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 3

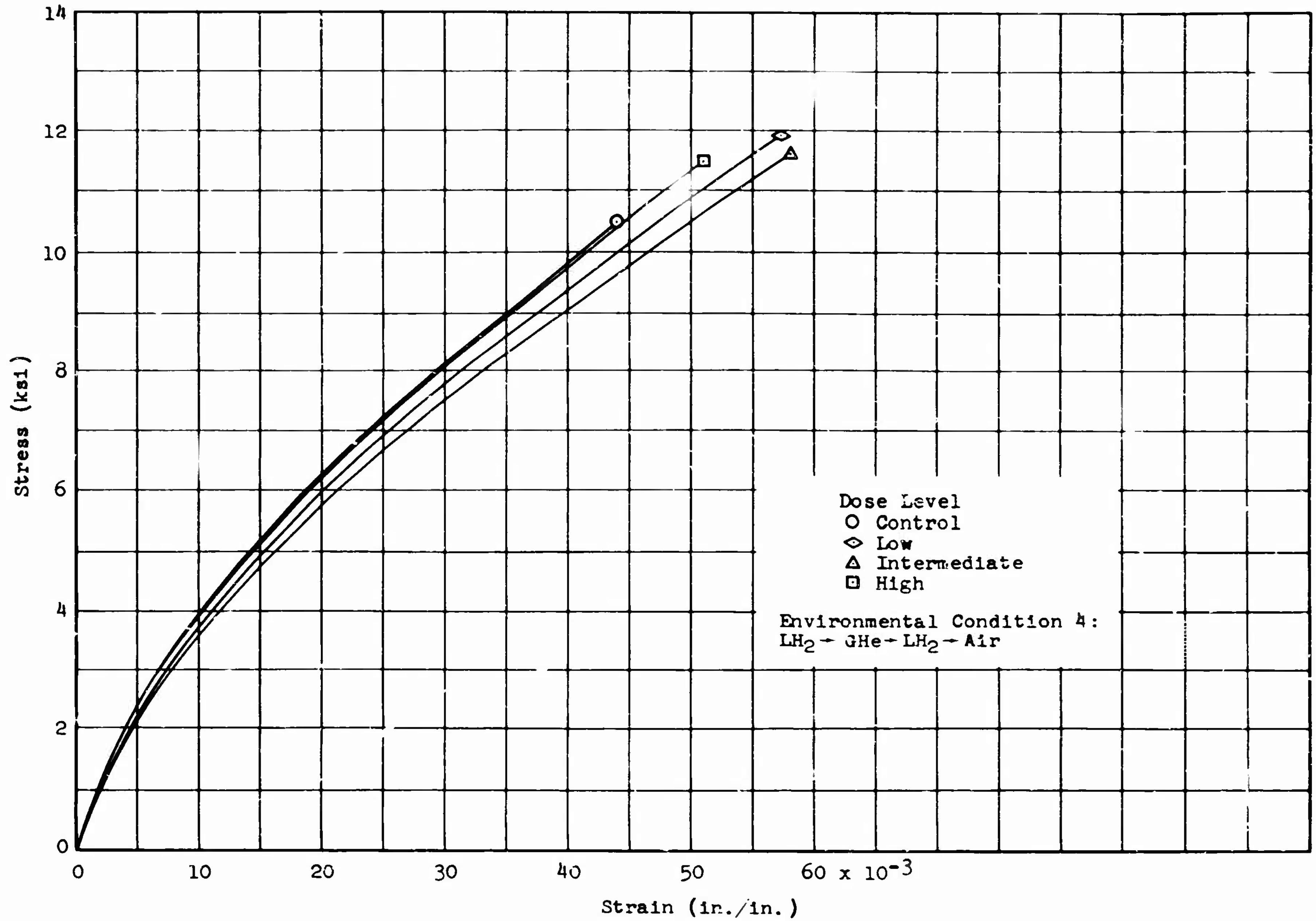


Figure 3-54 Superpolymer SP-3: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 4

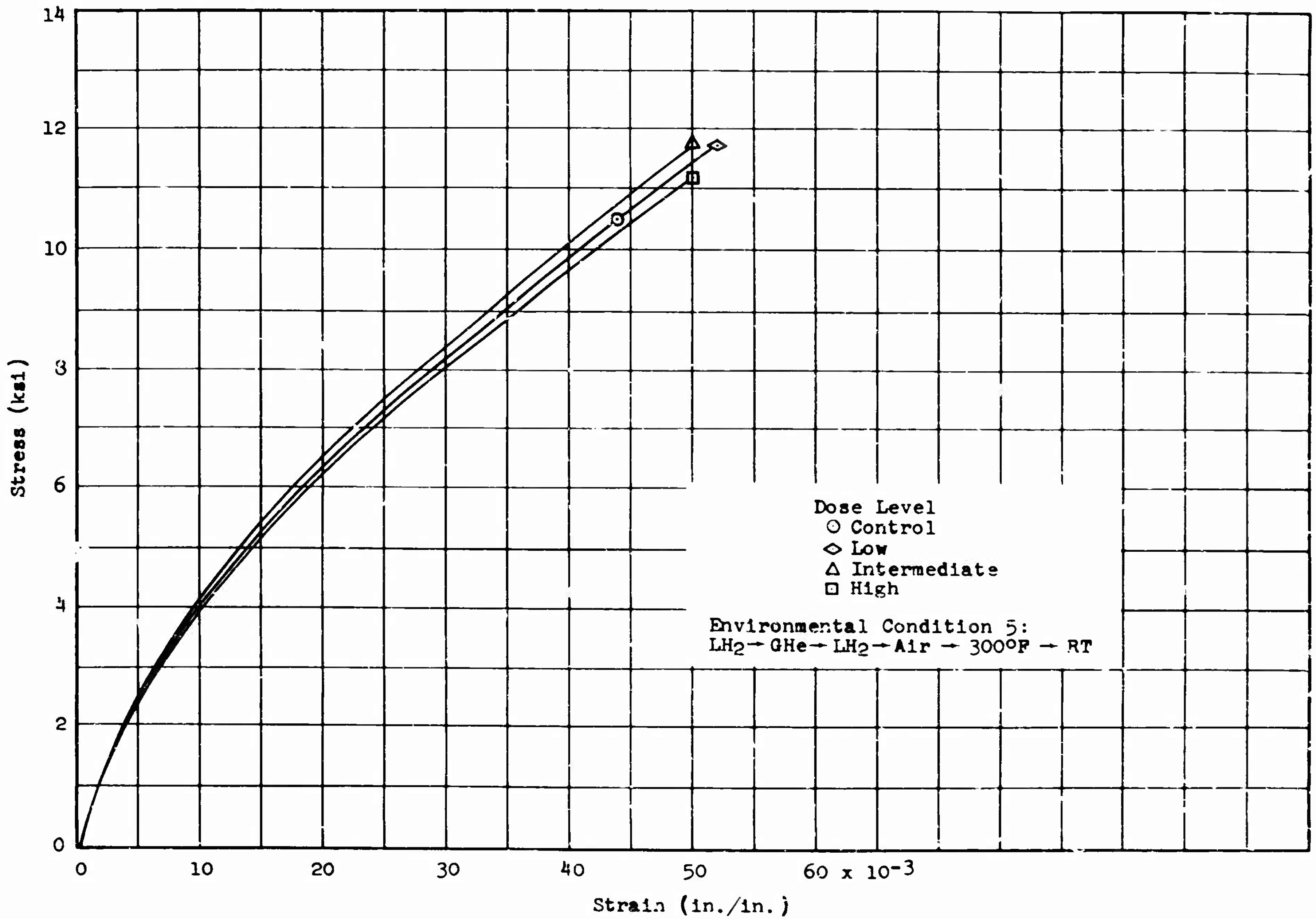


Figure 3-55 Superpolymer SP-3: Stress-Strain Curves Showing Effect of Dose Level on Specimens Tested at Environmental Condition 5

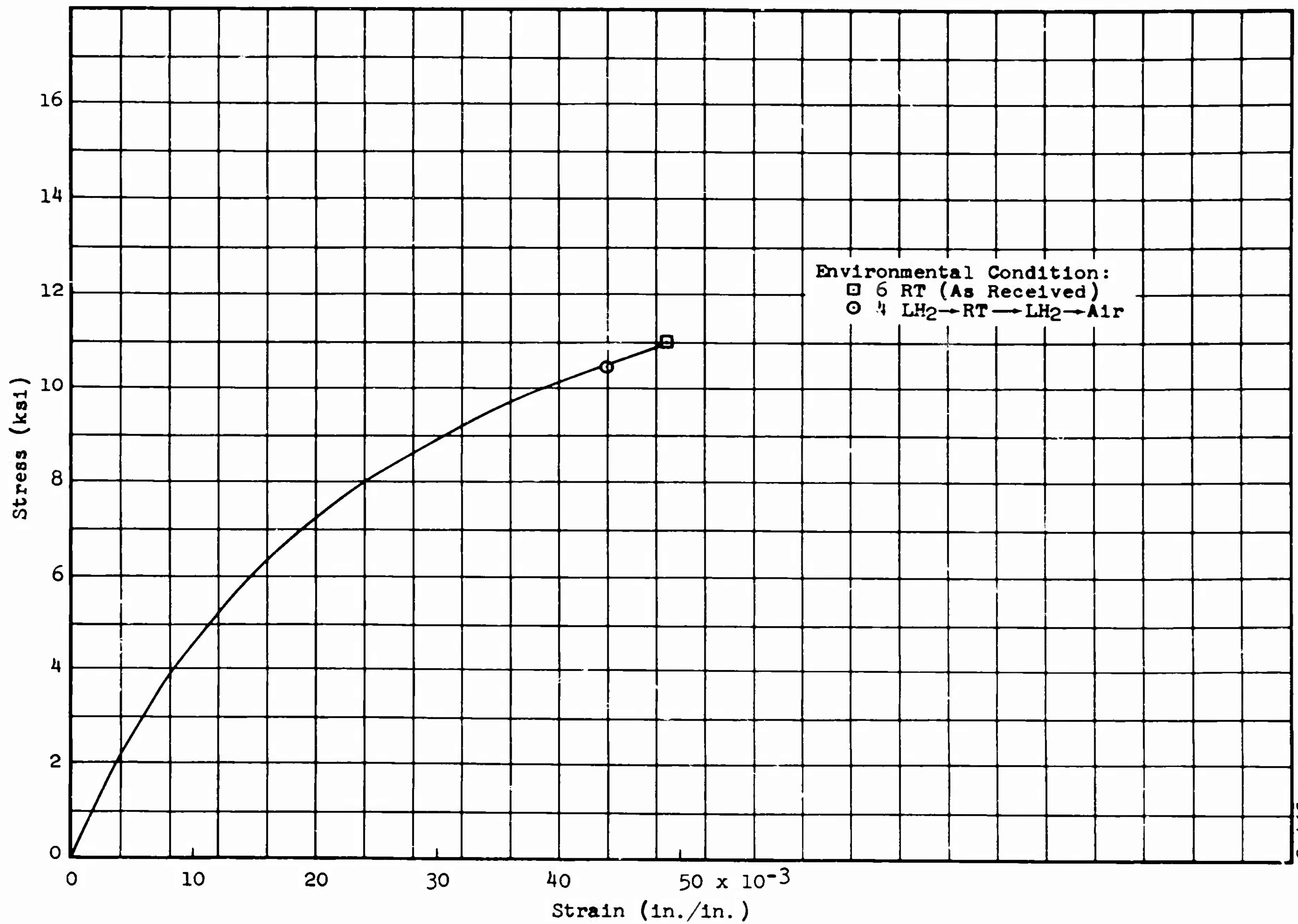


Figure 3-56 Superpolymer SP-3: Stress-Strain Curves of Control Specimens Showing Effect of Environmental Condition 4 vs 6

X-RAY DIFFRACTION STUDY

SPECIMEN		X-RAY METHOD	
Material	Superpolymer SP-3	Cu Tgt. Ni Fltr.	
Form	1/8-in. Section	R. M.	16-1-4
Condition	Machined	Slit	0.006

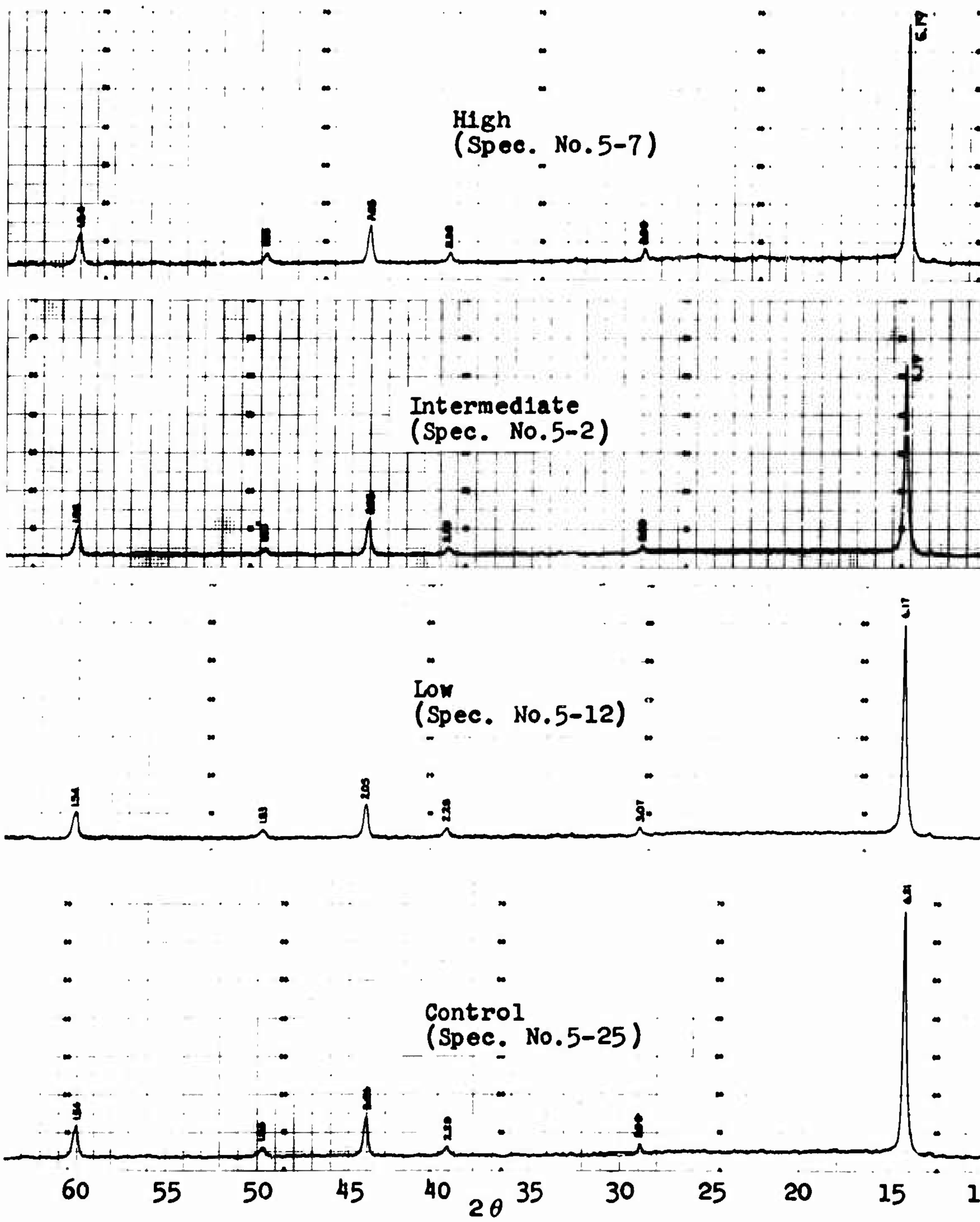


Figure 3-57 Superpolymer SP-3: Comparison of X-Ray Diffraction Data for a Typical Set of Specimens Exposed to Different Dose Levels and Tested at Environmental Condition 1

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3.3 Statistical Analysis

3.3.1 Discussion

The general over-all results of this experiment show that there are obvious test-temperature effects (LH_2 to Room Temperature) and radiation effects at the high-dose level (except for Superpolymer SP-3).

Before going into the details of a statistical analysis of the less obvious effects, it seems advisable to first discuss the lack of uniformity in the experimental units allocated to the various environmental treatment conditions for Armalon 405-L-112. A cursory analysis of the data for this material showed that there was considerably more variation within a group of specimens for the same condition than would normally be expected. A follow-up uncovered the fact that four different batches (sheets) of this material were used to make up the sample units for the experiment. These batches are denoted in this report as A, B, C, and D. As can be seen in Table 3-2, the between-batch variation is much larger than the variation within a batch (analysis of variance shows this result). When this occurs, special allocation of the sample units to the various environmental conditions is required so that the comparisons made between the various conditions are accurate and unbiased. As can be seen in the detailed data (Table 3-2), the control specimens for

condition 4 are all from batch A and the controls for condition 6 are from batch C. Thus, the observed difference in the ultimate-stress averages, 21.0 - 14.1 = 6.9 ksi, could be the result of the environmental condition 4 vs 6, batch difference, or a combination of both. In statistical terminology, the effect of the condition 4 vs 6 is confounded with batch differences.

Consider also the differences in the average values for condition 1 for

Low Dose - Control = 65.8 - 40.0 = 25.8 ksi

and

Intermediate Dose - Control = 42.8 - 40.0 = 2.8 ksi

The 25.8 difference is statistically significant; the 2.8 difference is not significant. This implies that the response of the material increases and then decreases as a function of dose. But since the batch variation is known, and the control average is from batches B and C and the low-dose average is from A and D, we have reason to suspect that the response to dose is confounded with the batch effect. Had one not known of the batch variation, the observed difference at the intermediate dose would be considered insignificant on the basis of the comparison made. A fair and more accurate estimate of the effect at condition 1 is possible by comparing the average values for the samples from batch B:

Intermediate Dose - Control = 22.2 - 37.6 = -15.4 ksi

This difference, -15.4, is statistically significant, which indicates that there is material degradation at the intermediate dose, contrary to the result obtained from the first analysis. This last comparison between samples from the same batch indicates the proper allocation one should make of the experimental material to the various conditions so as to make the comparisons fair and unbiased, i.e., one should make each group as near alike as possible by allocating (randomly) one sample from each batch.

Not only does batch variation affect the conclusions one can draw from the Armalon 405-L-112 data, it casts some doubts on the data on the other two Armalon materials. Although the variation is not so evident as that above, there are some peculiar effects not accounted for by just the sample variation. For example, the response curves for Armalon 405-CL-116 show considerable scatter from control data to the radiation data. For condition 1 there is a significant increase and then a decrease. For condition 2 there is a significant decrease. For condition 3 there is a significant decrease, then increase, then decrease. These results present a questionable response unless one realizes the possibility of the batch variation.

Neither is it reasonable to assume that Armalon 405-L-112

is inferior to Armalon 116 and 128. The high batch variation discovered in 112 may also be present in the other two materials, but by the chance selection of the sampling process, the batches for Armalon 116 and 128 were more alike than those selected for Armalon 112. Observe that had only batch A been selected for Armalon 112 the results would be somewhat in favor of Armalon 112, because for room-temperature condition 4 only batch A was used (except for one sample from batch C), and the average ultimate-stress values for each dose are larger than those for Armalon 116 and lower than those for Armalon 128.

3.3.2 Conclusions

Tables 3-6 through 3-10 contain the average values of the data for the various materials, test conditions, and radiation levels (controls to high dose). A statistical analysis was made by comparing the average values for each radiation level (low, intermediate, and high) with its corresponding control average. A "t" test of significance was used to evaluate the observed differences in the averages being compared. A probability level of 95% was used in the evaluation, with those differences that exceeded or equaled the 95% confidence level being noted in the tables. The average values in the tables are, in general, based on four observations each, except where noted (average/number of observations, n).

In Table 3-7, the average for each batch within a con-

Table 3-6

Statistical Analysis: Armalon 405-CL-116

Stress (ksi)				
Condition	Control	Low Dose	Intermediate Dose	High Dose
1	46.8	54.1*	50.5	19.3*
2	62.7	55.4*	53.5*	24.7*
3	N.T.[a]	46.9*	53.6*	26.2*
4	17.0	15.2*	13.0*	10.6*
5	N.T.[b]	14.2*	11.9*	N.T.
6	17.1			
Strain (%)				
1	3.1	3.8*	3.1	1.8/2*
2	4.5	3.8*	3.6*	2.6*
3	N.T.[a]	3.5*	4.0	2.5*
4	0.74	0.65	0.62	0.9
5	N.T.[b]	0.68	0.70	N.T.
6	1.08			

N.D. No data (testing difficulty or complete failure)
N.T. Not tested
[a]Use control average for condition 2
[b]Use control average for condition 4
*Statistically significant

Table 3-7

Statistical Analysis: Armalon 405-L-112

Stress (ksi)					
Condition	Batch	Control	Low Dose	Intermediate Dose	High Dose
1	A	c	72.0/2	63.4/2	N.D.
	B	37.6/2	c	22.2/2*	N.D.
2	A	c	71.5/1	69.2/2	N.D.
	B	35.6/2	33.7/1	27.0/1*	N.D.
3	B	N.T.[a]	36.7/2	27.0/2*	19.4/2*
	D	N.T.[a,c]	60.4/2	58.8/1	c
4	A	21.0/4	18.1/3*	15.6/4*	12.9/4*
5	A	N.T.[b]	N.T.	N.T.	13.1/4*
6	C	14.1/4			
Strain (%)					
1	A	c	5.6/2	4.4/2	N.D.
	B	3.6/2	c	3.0/2	N.D.
2	A	c	5.7/2	6.0/2	N.D.
	B	3.8/2	2.9/1	3.3/1	N.D.
3	B	N.T.[a]	4.8/2	4.2/2	N.D.
	D	N.T.[a,c]	5.1/2	4.0/1	c
4	A	0.9/3	0.53/3*	0.65/4*	0.68/4*
5	A	N.T.[b]	N.T.	N.T.	0.70/3*
6	C	1.2/4			

N.T. Not tested
N.D. No data (testing difficulty or complete failure)
[a]Use control average for condition 2
[b]Use control average for condition 4
[c]No samples of indicated batch tested at this radiation level
*Statistically significant

Table 3-8

Statistical Analysis: Armalon 510-L-128

Stress (ksi)				
Condition	Control	Low Dose	Intermediate Dose	High Dose
1	86.5	84.5	68.4*	32.4*
2	86.9	88.3	75.3*	34.5*
3	N.T.[a]	86.9	77.8*	16.6*
4	26.8	23.5*	18.5*	10.5*
5	N.T.[b]	24.8*	14.7*	8.9*
6	26.8			
Strain (%)				
1	5.4	4.7	4.8	N.D.
2	5.3	4.8	4.6	2.4/1*
3	N.T.[a]	5.2	5.2	1.9*
4	1.4	1.3	1.4/3	1.3
5	N.T.[b]	1.2/2	1.0*	1.4
6	1.6			

N.T. Not tested
N.D. No data (testing difficulty or complete failure)
[a]Use control average for condition 2
[b]Use control average for condition 4
*Statistically significant

Table 3-9

Statistical Analysis: Teflon FEP

Stress (ksi)				
Condition	Control	Low Dose	Intermediate Dose	High Dose
1	23.9	22.7	N.D.	N.D.
2	24.0	22.3*	15.2/3*	N.D.
3	N.T.[a]	23.9	19.1*	N.D.
4	3.6	3.0*	1.7*	N.D.
5	N.T.[b]	3.1*	1.8/2*	N.D.
6	4.0			
Strain (%)				
1	3.8	3.7	N.D.	N.D.
2	3.9	3.6	2.3/3*	N.D.
3	N.T.[a]	3.7	2.9*	N.D.
4	455	446	161*	N.D.
5	N.T.[b]	452	7.7/2*	N.D.
6	495			

N.T. Not tested
N.D. No data (testing difficulty or complete failure)
[a]Use control average for condition 2
[b]Use control average for condition 4
*Statistically significant

Table 3-10

Statistical Analysis: Superpolymer SP-3

Stress (ksi)				
Condition	Control	Low Dose	Intermediate Dose	High Dose
1	16.3	16.1	17.9	16.3
2	15.5	N.T.	N.T.	N.T.
3	N.T.[a]	16.8	17.2	16.0
4	10.5	11.9	11.6	11.5
5	N.T.[b]	11.7	11.8	11.2
6	11.0			
Strain (%)				
1	2.4	2.4	2.5	2.2
2	3.3	N.T.	N.T.	N.T.
3	N.T.[a]	3.4	3.9	3.6
4	4.4	5.7	5.8	5.1
5	N.T.[b]	5.2	5.0	5.0
6	4.9			

N.T. Not tested
[a]Use control average for condition 2
[b]Use control average for condition 4

dition for the various radiation levels is listed. The comparisons are thus made between the average values obtained from the same batch. These comparisons result in a smaller sample size than was planned, but the comparisons are unbiased with respect to the batch effect.

Because of the possible unknown batch effect for the Armalon material, cross comparisons between conditions within a given test temperature were not made. Also, comparisons between test temperatures (LH_2 and Room Temperature) are not made in this section because a statistical treatment would not add to what is already obvious.

A cross comparison between conditions within a given test temperature for Teflon FEP indicates no significant differences (probability, 0.95) with one exception. The measured strain for the intermediate-dose specimens tested at condition 4 was 161%, but only 7.7% for condition 5. This indicates a definite embrittlement resulting from subjecting the specimens to the +300°F temperature.

For Superpolymer SP-3 there are significant differences between conditions 1 and 3 at all radiation levels for the strain measurements. Although there are no indicated significant differences between the average values for Superpolymer, there are some significant changes in the variability. The

variation in the strain measurements at the different radiation levels are significantly larger than the variation in the corresponding control data for conditions 4 and 5. The variation in the stress data for conditions 4 and 5 increases with increasing dose.

3.4 Nuclear Measurements

3.4.1 Designed Exposures

Extensive nuclear measurements, performed prior to and during GTR-16, were utilized to provide data sufficient for a reliable characterization of typical radiation fields within test hardware located at the three irradiation positions surrounding the reactor closet. This information was utilized to stipulate equipment geometries required to achieve the different gamma dose levels as specified in the AGC test specifications. The following is a tabulation of the specified gamma exposure conditions for GTR-17, with the corresponding neutron integrated flux (E > 2.9 Mev), based on the reactor operating at a power level of 3 Mw and positioned 2 in. from the north face of the closet. The neutron flux for E > 1.0 Mev would be 2.8 times that shown in the table below.

Dose	Assembly Location	Run Time (hr)	Assembly-to-Closet Spacing	Exposure Gamma [ergs/gm(C)]	Exposure Neutrons (n/cm^2)
High	North	25	Normal	2.7×10^{10}	5×10^{15}
Intermediate	East	25	19 in.	5.4×10^{9}	7.8×10^{14}
Low	North	1	Normal	1.1×10^{9}	2.0×10^{14}

3.4.2 Measured Exposures

Nuclear detector packets were positioned in the following strategic locations in order to measure the neutron flux and the gamma dose in each of the three test assemblies:

1. At each pull rod position in front of and behind the specimens in the gas phase.

2. At each pull rod position in front of the dynamic specimens and also between the dynamic and static specimens in the liquid phase.

Each detector packet contained a bare and a cadmium-shielded phosphorous pellet and a sulfur pellet for determining the thermal- and fast-neutron ($E > 2.9$ Mev) fluxes, respectively. Each packet also contained a nitrous-oxide gamma dosimeter. A typical installation is shown in Figure 3-58. Gamma and neutron detectors were routinely processed in the NARF Nuclear Measurement Facility. The neutron data were reduced by standard foil techniques which have been programmed for use on the IBM 7090.

Figures 3-59, 3-60, and 3-61 show the gamma dose in ergs/gm(C) as a function of dosimetry packet position in the high-, intermediate-, and low-dose test assemblies, respectively. These data reflect a temperature correction which relates the moles of $N_2 + O_2$ produced in the dosimeter at $30^{o}C$ to that produced at LN_2 temperature ($-196^{o}C$). This correction factor yields very good

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Figure 3-58 Cryogenic Materials Test Assembly with Typical Dosimetry Packets Installed

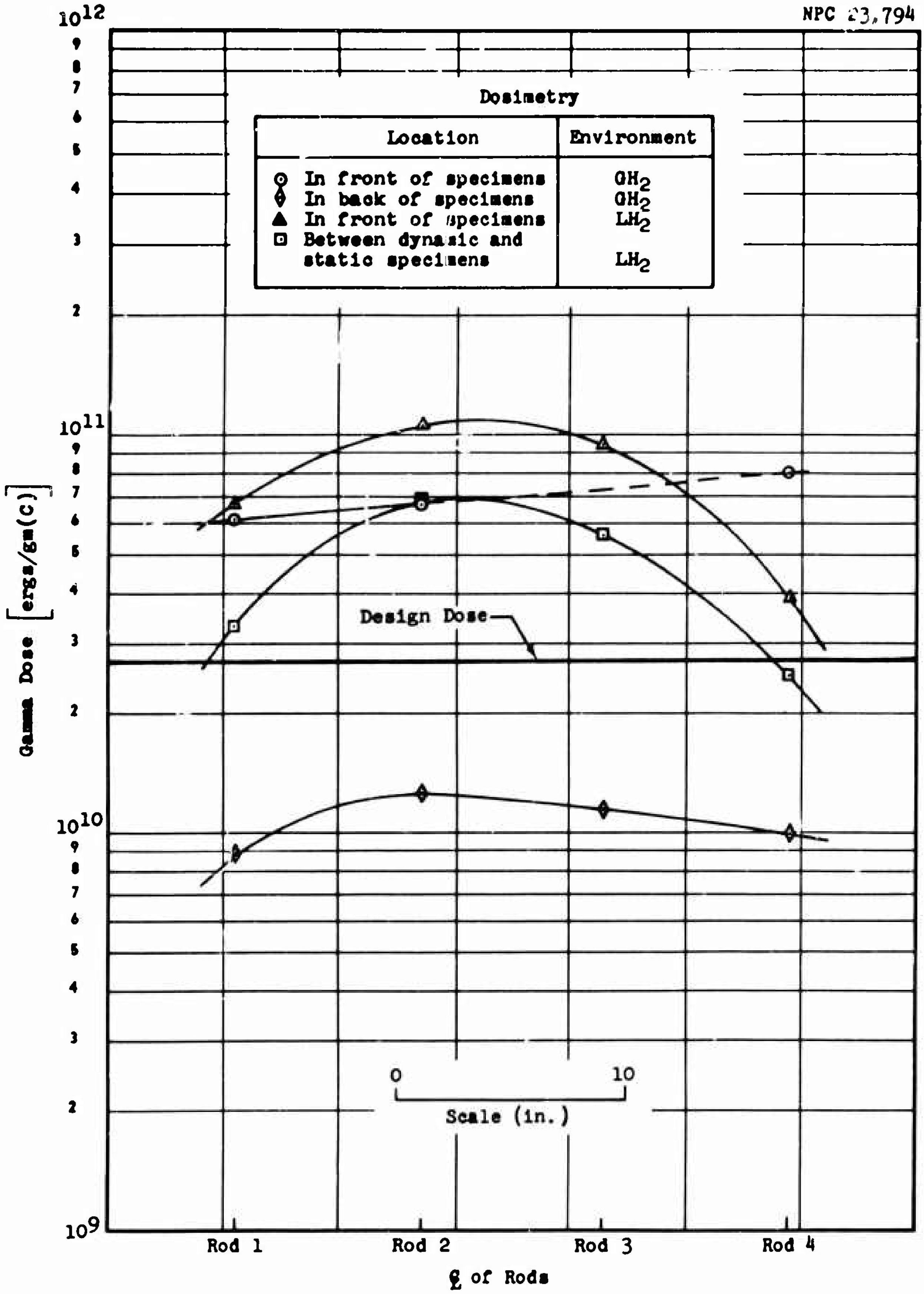

Figure 3-59 Measured Gamma-Dose Profile: High-Dose Assembly

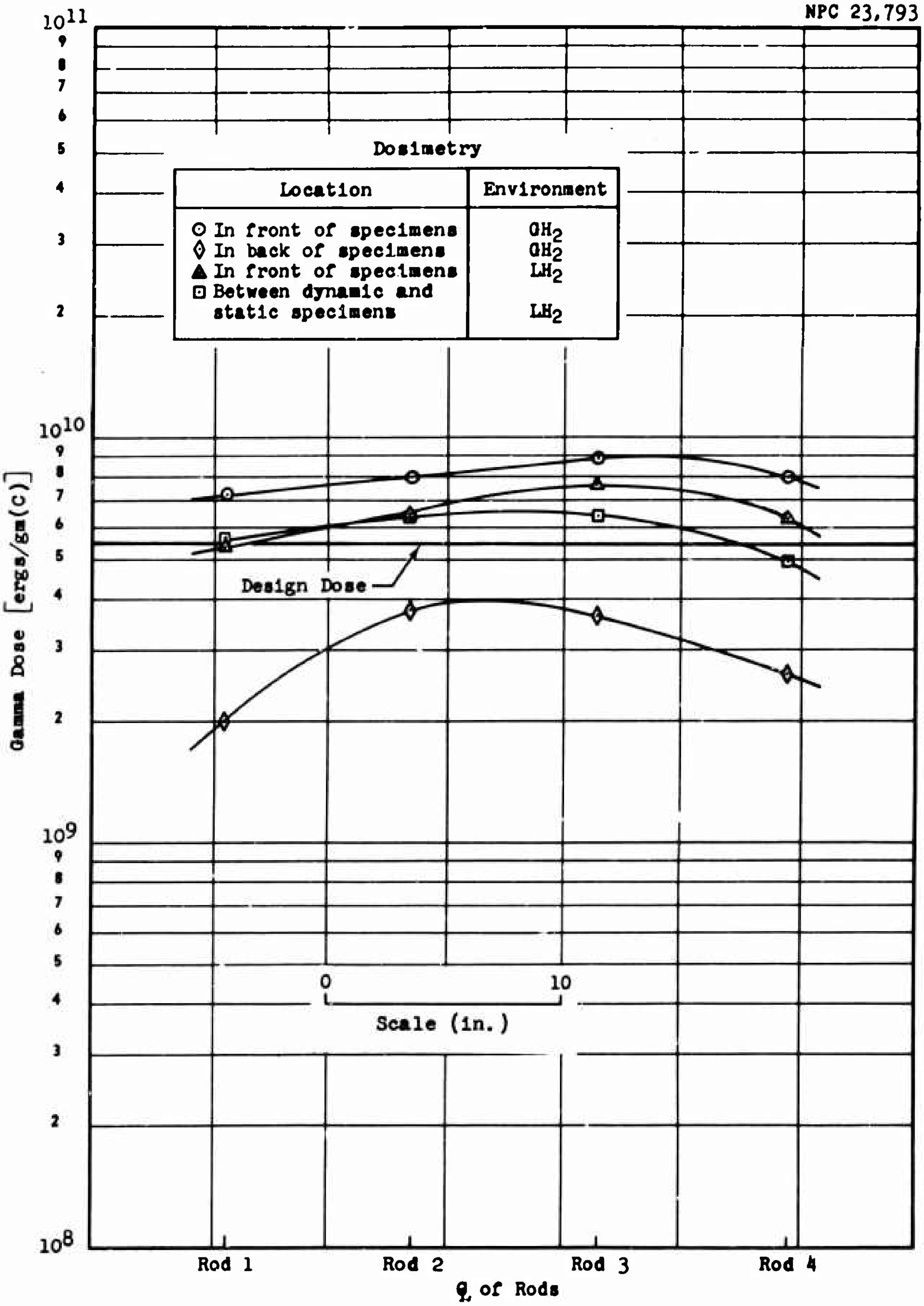

Figure 3-60 Measured Gamma-Dose Profile: Intermediate-Dose Assembly

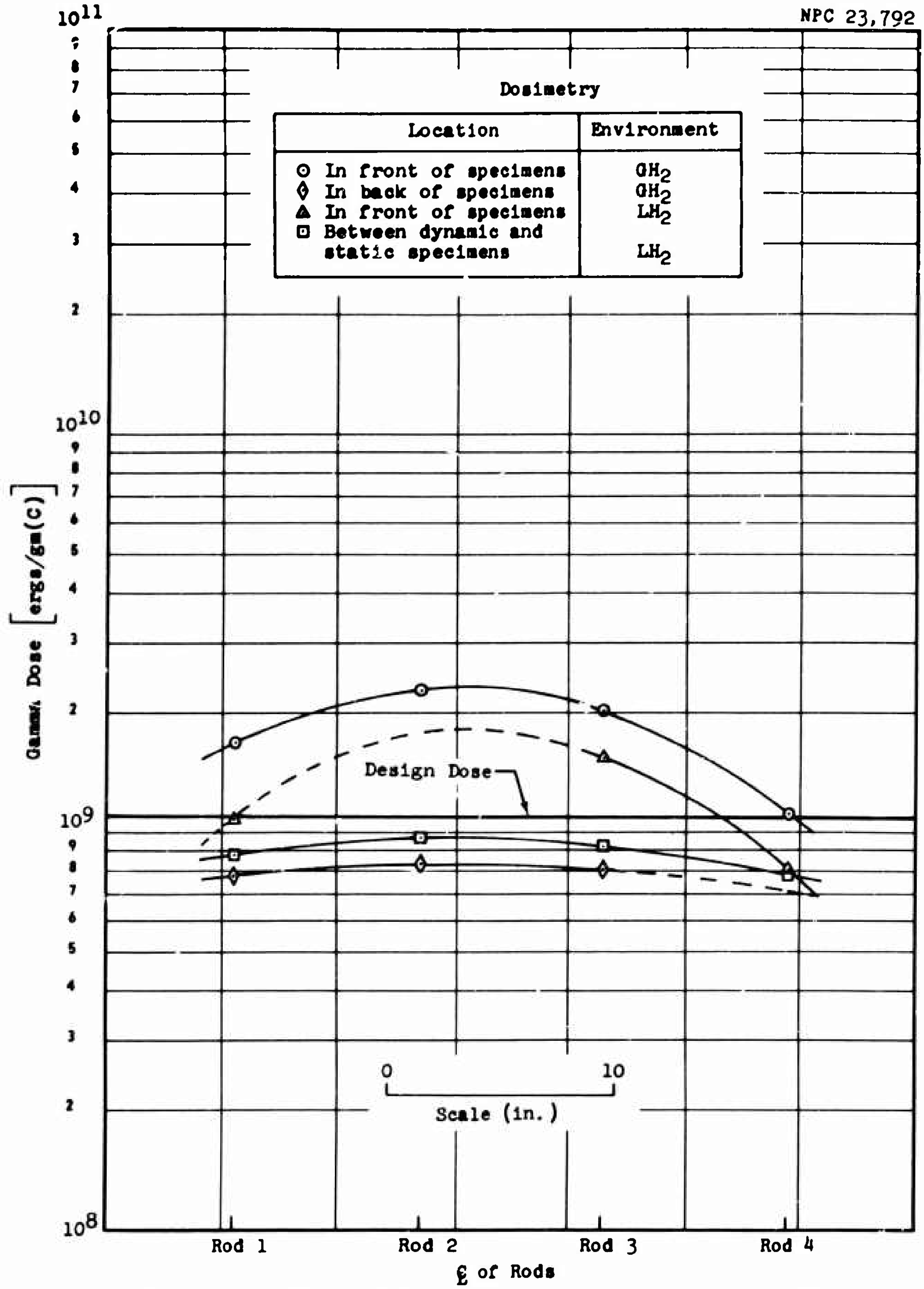

Figure 3-61 Measured Gamma-Dose Profile: Low-Dose Assembly

results when applied to the gamma doses measured in the gas phase where the temperature of the N_2O dosimeter is approximately -200°C. The gamma doses measured in the liquid phase are also reasonable when this correction factor is used, but there is indication that the moles of $N_2 + O_2$ produced in the dosimeter is probably greater at LH_2 temperature (-252°C) than at LN_2 temperatures. In order to present the most logical picture, therefore, measurements of the gamma doses in the liquid phase reflect a temperature correction factor. The correction factor assumes a linear relationship between the moles of $N_2 + O_2$ produced in the dosimeter at LN_2 temperature (-196°C), and that produced in the dosimeter at LH_2 temperature (-252°C). Since the relationship is linear between +30°C and -196°C, the assumption of linearity for LH_2 temperature is considered to be correct. Additional research into the response of the N_2O dosimeter when exposed to gamma radiation at LH_2 temperature is currently in progress.

The gamma dose measurements indicate that the design dose was achieved in all three configurations.

Figures 3-62, 3-63, and 3-64 show the integrated neutron flux in n/cm^2 ($E > 1.0$ Mev) as a function of packet position in the high-, intermediate-, and low-dose test assemblies, respectively. These data are derived from measurements of the neutron flux for $E > 2.9$ Mev made with sulfur pellets during

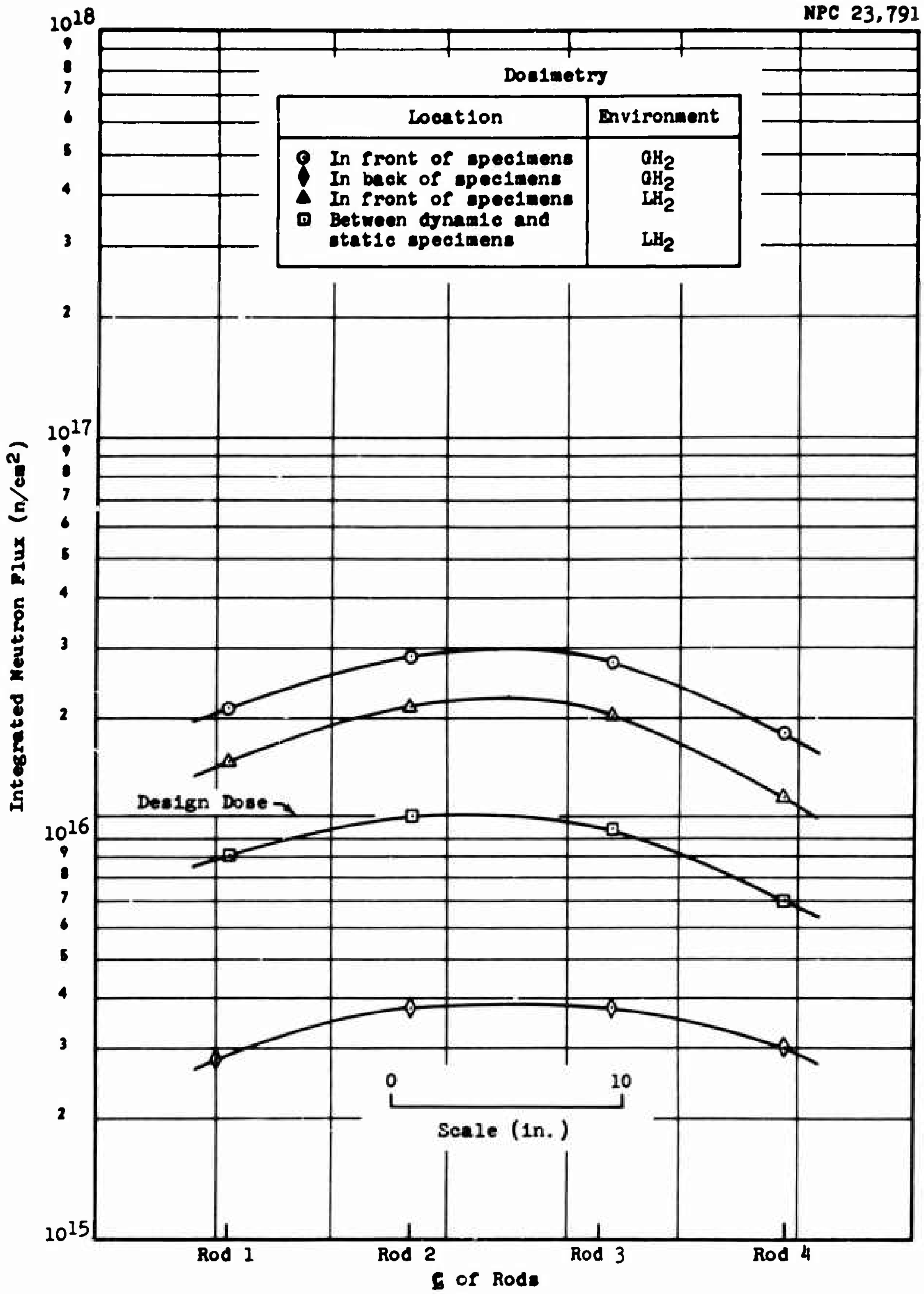

Figure 3-62 Measured Integrated-Neutron-Flux Profile: High-Dose Assembly

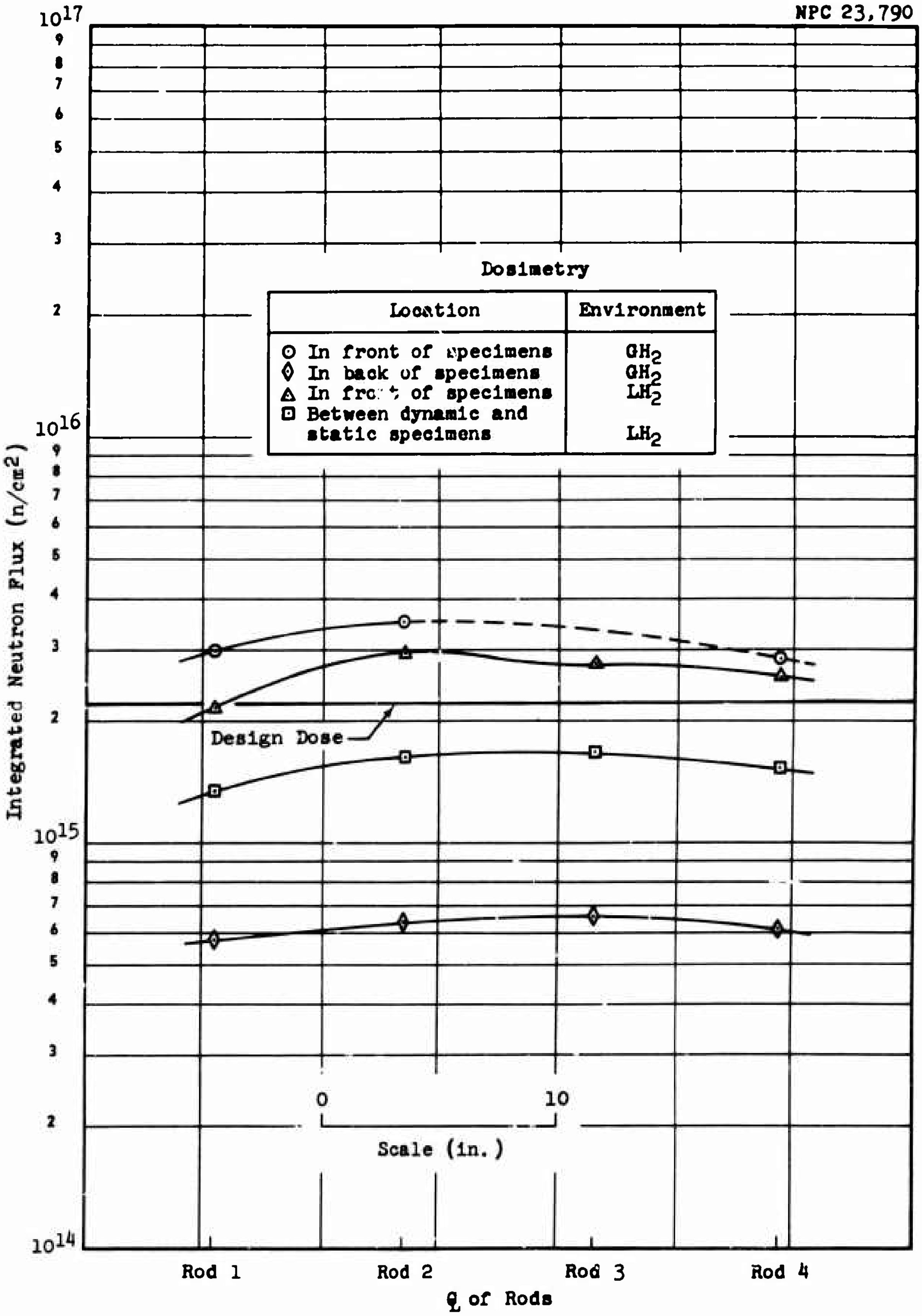

Figure 3-63 Measured Integrated-Neutron-Flux Profile: Intermediate-Dose Assembly

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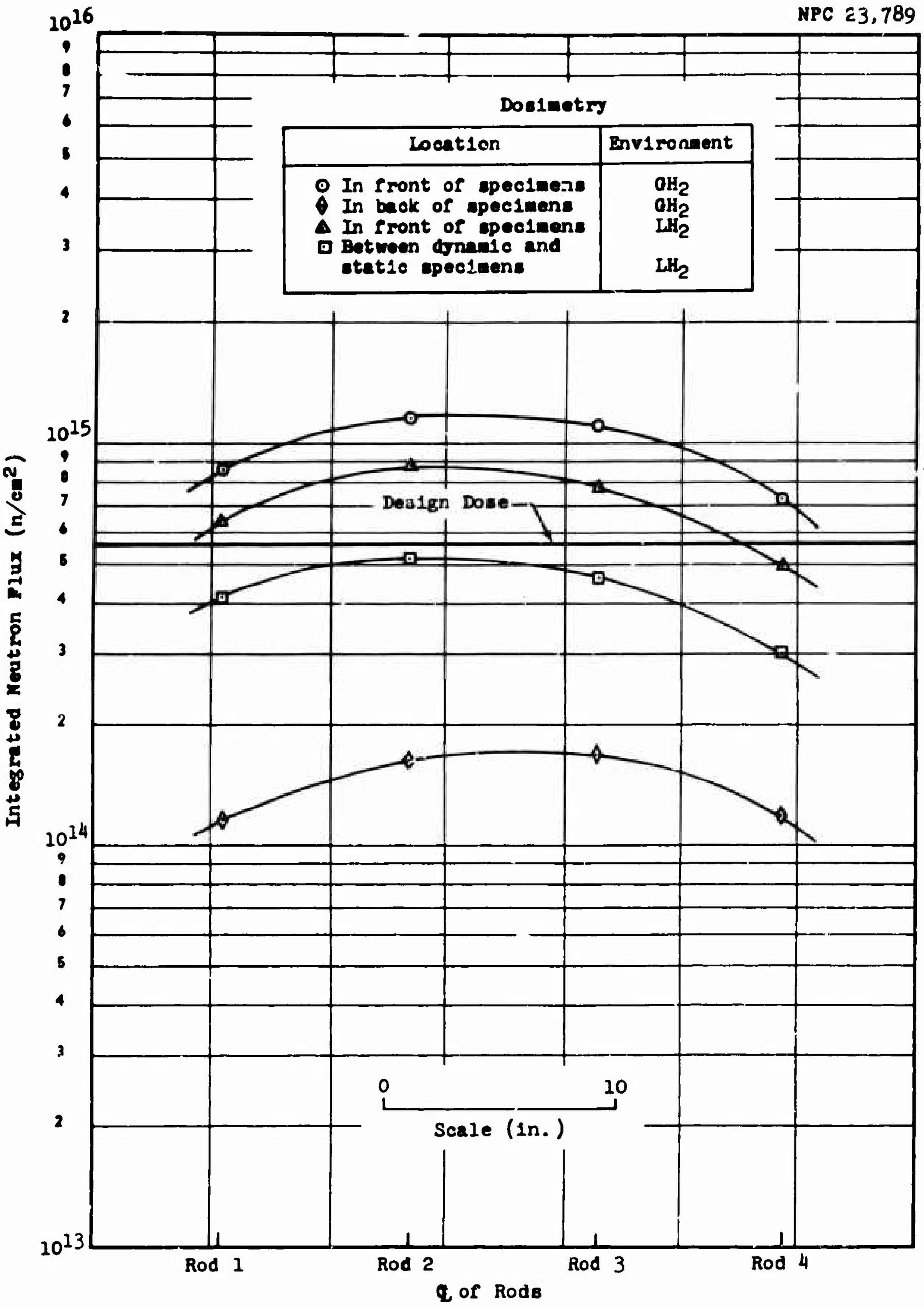

Figure 3-64 Measured Integrated-Neutron-Flux Profile: Low Dose Assembly

the irradiation. Mapping experiments made prior to this test indicate that the ratio of Φ for $E > 1$ Mev to Φ for $E > 2.9$ Mev is equal to 2.8. Applying this factor to the measured sulfur flux yields a value of the flux for $E > 1$ Mev.

The relative irradiation location of all specimens in each of the three test assemblies is shown in Table 3-11.

Table 3-11

Relative Location of Irradiated Specimens in Cryogenic Materials Test Assemblies

Low-Dose Assembly

Dyn. Pull Order	Specimens Mounted in Pull Assembly			
	Rod 1	Rod 2	Rod 3	Rod 4
1	5-9	5-10	5-11	5-12
2	4-45	4-46	4-47	4-48
3	4-69	4-70	4-71	4-72
4	1-45	1-46	1-47	1-48
5	1-69	1-70	1-71	1-72
6	3-45	3-46	3-47	3-48
7	3-69	3-70	3-71	3-72
8	2-45	2-46	2-47	2-48
9	2-69	2-70	2-71	2-72
Static Attached to Upper Clevis Only	1-9 3-9 2-9 4-9 5-52	1-10 3-10 2-10 4-10 5-53	1-11 3-11 2-11 4-11 5-54	1-12 3-12 2-12 4-12 5-55

Specimens Mounted on Static Rack Behind Pull Rods

5-21	4-53	1-53	3-53	2-53	1-21	3-21	4-21	5-60
5-22	4-54	1-54	3-54	2-54	1-22	3-22	4-22	5-61
5-23	4-77	1-77	3-77	2-77	1-23	3-23	4-23	5-62
5-24	4-78	1-78	3-78	2-78	1-24	3-24	4-24	5-63

Intermediate-Dose Assembly

Dyn. Pull Order	Specimens Mounted in Pull Assembly			
	Rod 1	Rod 2	Rod 3	Rod 4
1	5-1	5-2	5-3	5-4
2	4-37	4-38	4-39	4-40
3	4-61	4-62	4-63	4-64
4	1-37	1-38	1-39	1-40
5	1-61	1-62	1-63	1-64
6	3-37	3-38	3-39	3-40
7	3-61	3-62	3-63	3-64
8	2-37	2-38	2-39	2-40
9	2-61	2-62	2-63	2-64
Static Attached to Upper Clevis Only	1-1 3-1 2-1 4-1 5-44	1-2 3-2 2-2 4-2 5-45	1-3 3-3 2-3 4-3 5-46	1-4 3-4 2-4 4-4 5-47

Specimens Mounted on Static Rack Behind Pull Rods

5-13	4-49	1-49	3-49	2-49	1-13	3-13	4-13	5-56
5-14	4-50	1-50	3-50	2-50	1-14	3-14	4-14	5-57
5-15	4-73	1-73	3-73	2-73	1-15	3-15	4-15	5-58
5-16	4-74	1-74	3-74	2-74	1-16	3-16	4-16	5-59

High-Dose Assembly

Dyn. Pull Order	Specimens Mounted in Pull Assembly			
	Rod 1	Rod 2	Rod 3	Rod 4
1	5-5	5-6	5-7	5-8
2	4-41	4-42	4-43	4-44
3	4-65	4-66	4-67	4-68
4	1-41	1-42	1-43	1-44
5	1-65	1-66	1-67	1-68
6	3-41	3-42	3-43	3-44
7	3-65	3-66	3-67	3-68
8	2-41	2-42	2-43	2-44
9	2-65	2-66	2-67	2-68
Static Attached to Upper Clevis Only	1-5 3-5 2-5 4-5 5-48	1-6 3-6 2-6 4-6 5-49	1-7 3-7 2-7 4-7 5-50	1-8 3-8 2-8 4-8 5-51

Specimens Mounted on Static Rack Behind Pull Rods

5-17	4-51	1-51	3-51	2-51	2-17	3-17	4-17	5-64
5-18	4-52	1-52	3-52	2-52	2-18	3-18	4-18	5-65
5-19	4-75	1-75	3-75	2-75	2-19	3-19	4-19	5-66
5-20	4-76	1-76	3-76	2-76	2-20	3-20	4-20	5-67

APPENDIX

GTR RADIATION EFFECTS TESTING SYSTEM

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APPENDIX

GTR RADIATION EFFECTS TESTING SYSTEM

The GTR Radiation Effects Testing System is located in the Reactor Operations Area at the north end of the NARF complex. Figure A-1 is a plan view and Figure A-2 is a cutaway view of the system. A closeup of the irradiation test cell and the reactor tank is pictured in Figure A-3. During operation, the reactor is moved into the closet-like structure built into the north wall of the GTR tank. Items to be irradiated can be located on the north, east, or west sides of the closet, as indicated in the figures.

The reactor closet is constructed of 1-in. aluminum plate and is partially covered by 1/4-in.-thick boral to attenuate thermal neutrons. The boral extends 36 in. east and west from the closet along the tank wall and 36 in. up and down from the horizontal centerline of the reactor core. The centerline is 57 in. above the test-cell floor.

The Ground Test Reactor (GTR) is a heterogeneous, highly enriched, thermal reactor that utilizes water as neutron moderator and reflector, as radiation shielding, and as coolant. Maximum power generation is 3 Mw. The GTR, in an aluminum enclosure to facilitate cooling-water flow, is suspended by an

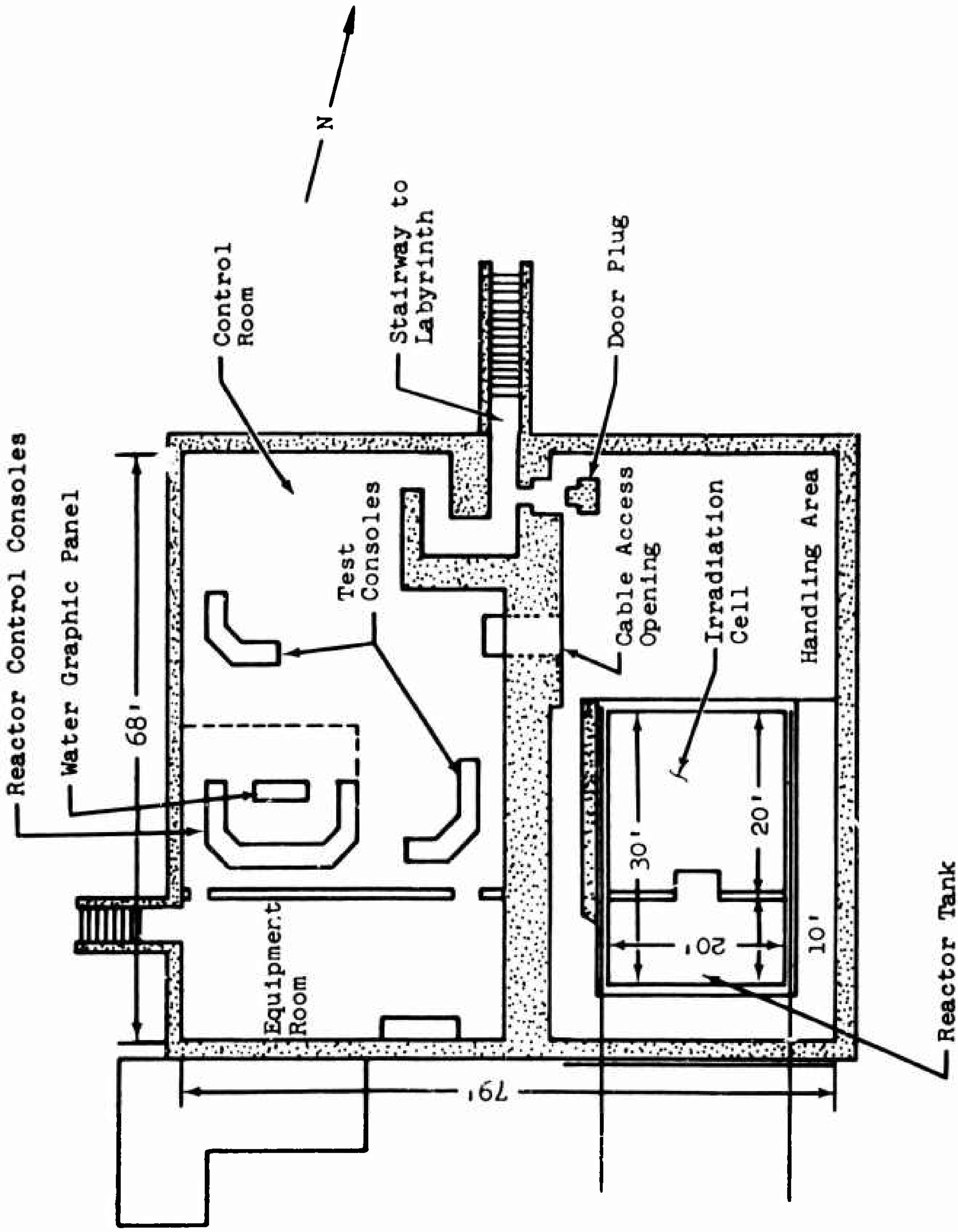

Figure A-1 Operations Building and GTR Facility

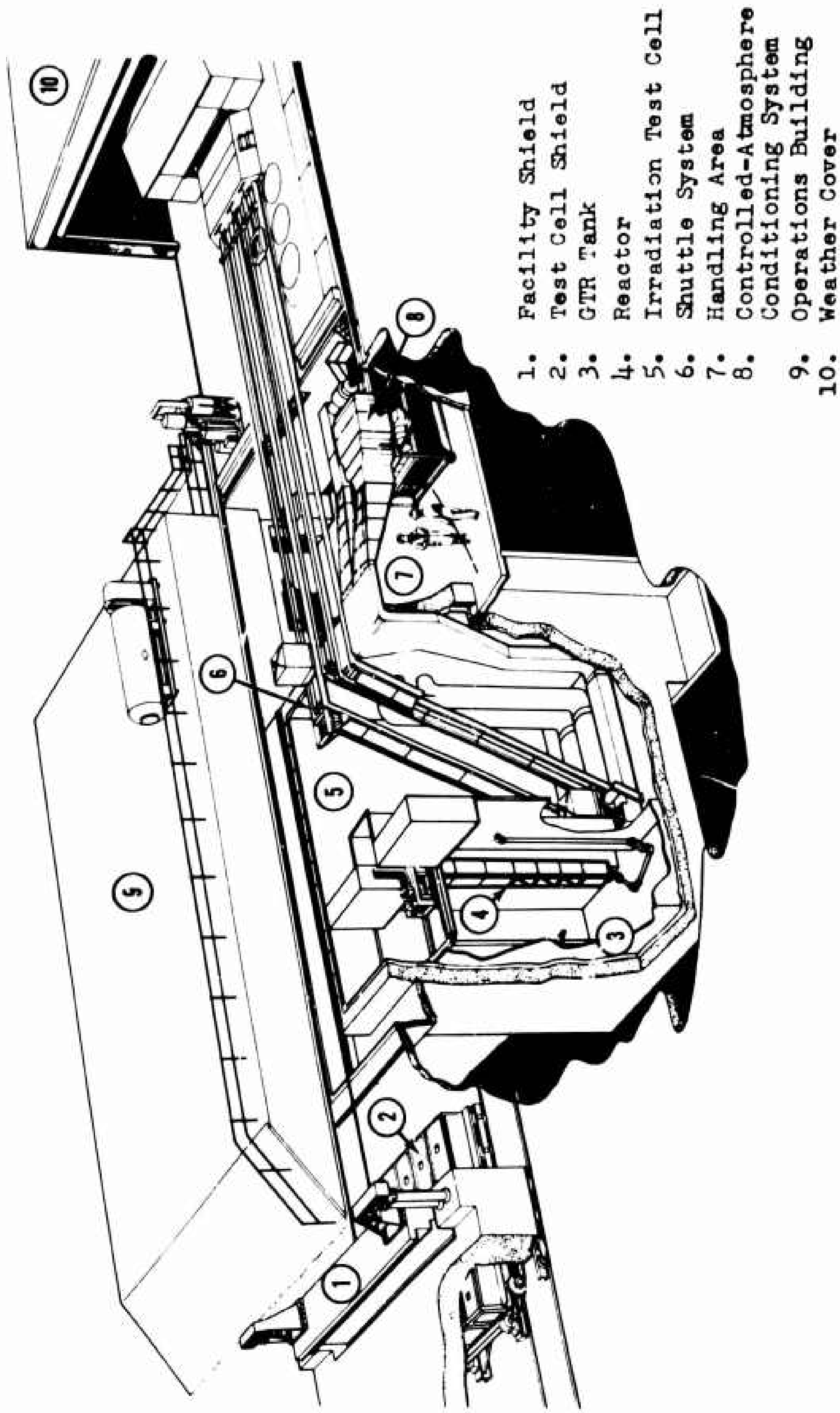

Figure A-2 Cutaway View of GTR Radiation Effects System

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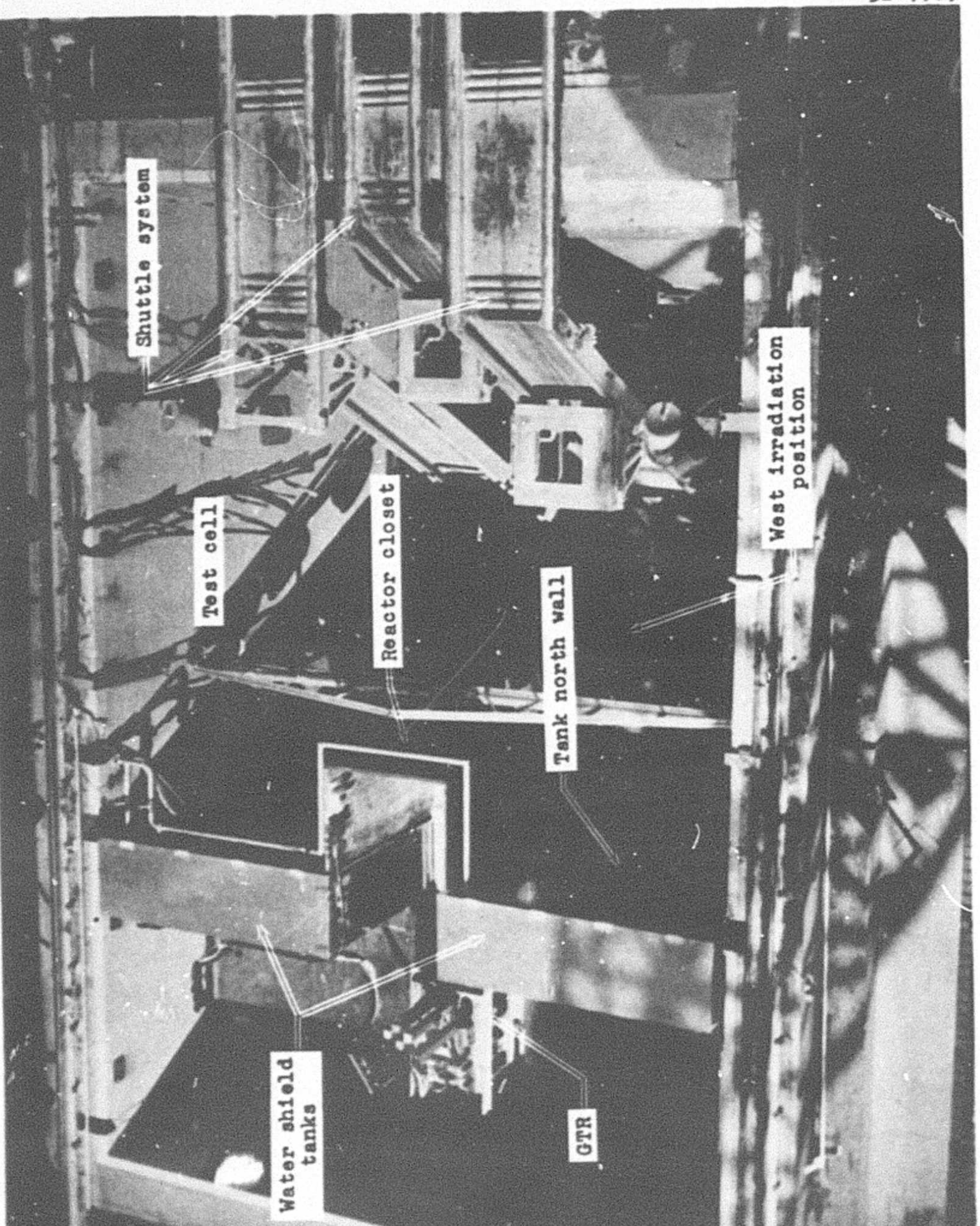

Figure A-3 Irradiation Test Cell and Reactor Tank

open framework that is carried on a horizontal positioning mechanism at the top of the reactor tank. This mechanism permits the reactor to be positioned at distances ranging from 2 to 87 in. from the north face of the closet.

Adjacent to the north wall of the irradiation cell is the handling area. In this area, various connections are made for cryogenic, hydraulic, and pneumatic equipment.

An integral part of the GTR testing facility is the shuttle system, which is used to move test assemblies into irradiation position. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the reactor closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be operated from either the control room or the dolly motor-drive shed on the north ramp. Full-coverage televiewing of the entire shuttle system is provided by means of a closed-circuit television in the control room.

The control room (Fig. A-1) is a below-grade, reinforced concrete structure adjacent to the GTR system. The control room provides a shielded area for reactor instrumentation, control consoles, and test systems as well as special test equipment needed to conduct radiation experiments.

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